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FRANZ YUL'YEVICH LOEWINSON-LESSING AND SOME BASIC PROBLEMS OF MODERN PETROGRAPHY (THE HUNDREDTH ANNIVERSARY OF HIS BIRTH, 1861-1961)[1]

by

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Sane multum illi egerunt qui ante nos fuerunt.
Seneca
Lest the precious heritage of the past be for-
gotten, it is well to pause now and then, and to
look back in order better to evaluate the present
status of our knowledge and its future trend.
F. Yu. Loewinson-Lessing: "Introduction to
the History of Petrography", 1936.

There always have been great names at the
sources of any discipline, symbolizing its pro-
gress and, in a final count, its present state.
Speaking of chemistry, we remember Men-
deleyev; progress in crystallography and crys-
tal optics is inseparable from Ye. S. Fedorov's
name, and that of geochemistry from V. I.
Vernadskiy's. In the same organic relation to
Russian and international petrography stands
the name of F. Yu. Loewinson-Lessing whose
hundredth birthday anniversary we celebrate
this month.

Time is the best criterion of merit. Only
noble metals and truth are enduring. Like
space, time provides the perspective necessary
for a correct evaluation of a work of art and of
a human mind.

The historical perspective is deep enough
for us to see that the main works of F. Yu.
Loewinson-Lessing have withstood the test of
time well as the firm foundation of modern
petrography. The hundredth anniversary of a
great scientist thus occurs at a time of triumph
of his scientific ideas.

HIS LIFE

"Inspiration is as essential in poetry as in geo-
metry. "
A. S. Pushkin, 1826
"Natural science progresses in three ways: ob-
servation, experiment, and speculation; i. e. ,
through ideas (hypotheses). "
F. Yu. Loewinson-Lessing, Progress of Petro-
graphy in Russia, 1923.

A son named Franz was born to the family
of a doctor popular in old Saint Petersburg, on
March 9 (February 23) 1861. He was to be a
future member of the U. S. S. R. Academy of
Sciences, Laureate of the French Academy of
Sciences, and Honorary Member of the London,
American, and Belgian Geological Societies.

An excellent education (he was proficient in
three European languages), the classical
Gymnasium, and finally the Natural Sciences
Division of the Physico-Mathematics Depart-
ment of Saint Petersburg University, prepared
the young Loewinson-Lessing for his future
scientific work. Along with an inquisitive mind,
they promoted the development of a broad
range of interests, the prerequisite for a true

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scientist. An enormous erudition became a mark of this outstanding Russian petrographer.

Upon his graduation in 1883, with a gold medal, F. Yu. Loewinson-Lessing was retained by the University for professorial training. In that summer he was invited by A. A. Inostrantsev to participate in a field trip to the Olonetsk region. The trip to Lake Ladoga, resulting in his first published work [1], was the beginning of a long series of field and theoretical studies which combined a keen power of observation and the ability for penetrating and ingenious conclusions. Having defended his Master's thesis in 1889 [22], the young scientist was appointed Assistant Professor at Saint Petersburg University.

The gradual formation of his scientific interest was strongly influenced by two outstanding teachers: the pedologist and mineralogist, Professor V. V. Dokuchayev, and the geologist, Professor A. A. Inostrantsev. They were partly responsible for the unusually wide range of his interests, with his works (especially the earlier ones) including studies in geology, pedology, paleontology, stratigraphy, mineralogy, crystallography, and engineering geology. However, from his first independent work to the end of life, F. Yu. Loewinson-Lessing was a petrographer, above everything else. It is by his works in that field that he will be remembered by generations of scientists.

In 1892, F. Yu. Loewinson-Lessing was appointed Professor of Mineralogy at Derpt (now Tartus) University. It was perhaps at that period that he initiated a new trend in petrography which has determined its progress to a considerable extent.

As early as 1897, he was among the principal Russian delegates at the Seventh International Geological Congress in Saint Petersburg. His paper on a chemical classification of extrusive rocks, a resumé of his Doctoral thesis, was an important mark in the history of world petrography. That paper was a culmination of a series of achievements and the beginning of a new stage in that science.

For the next 40 years, up to the Seventeenth International Congress in Moscow, in 1937, he did the honors of representing the petrographers of his country.

The year 1902 witnessed the opening of the broadly conceived and well equipped Petersburg Polytechnical Institute. F. Yu. Loewinson-Lessing, by then well known throughout Europe, was invited to head the chair of geology and mineralogy at the Department of Metallurgy. He was appointed, simultaneously, Professor of Geology at the Bestuzhev School for Women, where he taught until 1920 when his students were transferred to the University.

Studies of the chemistry of rocks and of the relationship between their composition and origin, initiated back at Derpt University, found an especially favorable climate at the Polytechnical Institute. The new professor, assisted by his students and fellow-teachers (petrographers, chemists, metallurgists), set up a large and momentous series of studies in an excellent laboratory. Physicochemical equilibria of silicate systems, related to the problem of petrogenesis were studied here for the first time anywhere, including the famous geophysical laboratory at Washington.

The following two decades turned out to be quite fruitful. They enriched Russian petrography in important regional, experimental, and theoretical works — by Loewinson-Lessing himself as well as by his pupils. Outstanding scientists of a later period rapidly advanced among his students. They included Academicians D. S. Belyankin, D. I. Shcherbakov, and Professors P. I. Lebedev, A. S. Ginzberg, I. A. Preobrazhenskiy, I. I. Ginzburg, and others. There was by that time a definite school of Russian petrographers headed by a scientist brimming with creative energy.

It is beyond the scope of a brief article to take in all aspects of the intensive activity of a man at that happy stage when the full bloom of his talent is as yet unbridled by that melancholy lot of old age — physical infirmity. F. Yu. Loewinson-Lessing always believed that the most momentous problems in petrography are solved only in a harmonious union of field work, laboratory analysis, and constructive synthesis.

He visited the Caucasus, Mugodzhary, and the Urals. One after another came his brilliant works on volcanism and lavas of the Central Caucasus; gabbroid complexes and platinum and iron-ore deposits in the Northern Urals; and the ancient extrusive series of Mugodzhary. Each of those works enriched the regional petrography in precise descriptions, and theoretical petrography in new observations and inferences. Suffice it to say that it was then that he formulated the notion of near-surface intrusions (laccolithic volcanoes) and complex volcanic-plutonic formations (e. g., in the Caucasus); advanced the idea of mineralizing magma (Blagodat Mountain); worked out a theory of the origin of banded gabbros (Urals); and demonstrated once more the immiscibility of basic lavas (Mugodzhary).

Of particular importance is a series of his works in connection with a railroad passage and a 22-verst (about 15 miles) tunnel across the Main Caucasian Range, worked out by the Ministry of Ways and Communications, shortly before the First World War. In a number of articles, F. Yu. Loewinson-Lessing summarized the data of stratigraphy, structural geology, petrography, and geophysics, leading to a well substantiated recommendation.

In the meantime, experimental study was carried on in the Polytechnical Laboratory, on the crystallization of eutectic melts; the genetic difference between a porphyry (extrusive) and porphyritic (intrusive) structure was determined as a by-product.

During the same period, F. Yu. Loewinson-Lessing substantially advanced our knowledge in the field of theoretical synthesis. He successfully developed the theory of differentiation and nature of magma and deepened and refined many problems in the systematics and classification of extrusive rocks.

In the stormy days of the Great October Socialist Revolution and in the following three years, when the numerous nationalities of Russia were delivered from age-long bondage and given a chance to develop their material and spiritual creative potential on a scale hitherto unthinkable, F. Yu. Loewinson-Lessing always stood in the front ranks of the progressive Russian intelligentsia. Along with other progressive scientists of that time, he ardently participated in the restoration of the national economy of the young Republic of Soviets, shattered by two wars.

In 1917, he was elected Chairman of the Division of Building Stone, organized at his initiative at the Commission For the Study of the Productive Potential of Russia, at the U.S S.R. Academy of Sciences. At the same time he was entrusted with organizing the Pedology Division and the Commission on Platinum. In 1920-1922 he was in charge of a geological survey for the construction of the pioneer of socialist electrification, the Svir Hydroelectric Station. All that meant a tremendous expansion of the activities of this scientist, as much a symbol of the time as a testimony to his exceptional creative capacity.

However, then as before, the deepening of human knowledge and its propagation among the young remained his principal and favorite task.

In 1920, F. Yu. Loewinson-Lessing took the place of his teacher A. A. Inostrantsev (who died in 1921) as Professor of Petrography and Geology at Petersburg (subsequently Leningrad) University. The circle of events closed: a world-known scientist came back to one of the oldest schools of the country, where he, as a young man, had matriculated 41 years ago. From then on to the end of his days he would deliver to hosts of students his lectures, classic in depth and clarity, within the walls of Peter's old Kamer-Kollegium.

The world-wide recognition of the head of the Russian petrographic school was bearing fruit. In 1919, F Yu. Loewinson-Lessing was elected Petrographer of the All-Union Geological Institute; the London, Belgian, and American Geological Societies elected him Honorary Member and announced it with flattering certificates. The French Academy of Sciences awarded him a special prize, in 1924, in consideration of his outstanding merit in the field of petrography. In 1925, his own country granted him her highest award. Upon the representation by the Dean of Russian Geologists, A.P. Karpinskiy, President of the U.S.S.R. Academy of Sciences, and by Academicians V.I. Vernadskiy and A. Ye. Fersman, he was unanimously elected Member of the Academy. At the same time, he became Director of the Geological Museum out of which the Institute of Petrography was organized in 1920, the first in our country; it was named subsequently, but during the lifetime of its founder, after him.

All those events led to the culminating stage in the creative life of the venerable scientist; he now had a huge following of collaborators and pupils from the two largest Leningrad schools, his scientific research institute, and a long train of divisions, commissions, and expeditions of the Academy.

The extraordinarily broad and diversified field of activity of the last fifteen years of this first Russian Academician and Petrographer is still waiting for comprehensive study. Even the most detailed of the scientific biographies, the well-known book by P.I. Lebedev [19], merely touches upon the main fields of his life's work and confines itself to those scientific and social affairs most affected by this great man.

Indeed, a more impressive list of tasks and responsibilities is difficult to compile. Only his inexorable striving for a goal and his tremendous capacity for work, coupled with an extraordinary erudition, could sustain that mighty scientific and organizational effort in an old man. He was Director of the Institutes of Petrography and Pedology at the Academy of Sciences; Director of the Institute of the Earth's Crust at Leningrad University and the Volcanology Station in Kamchatka; Chairman of the Azerbaydzhanian and Armenian Affiliates of the Academy, subsequently the Azerbaydzhanian and Armenian Academies of Sciences; Chairman of the Yakutian, Caspian, and Quaternary Commissions of the Academy; and scientific leader of the Armenian, South Osetian, Svanetian, and Kamchatka Joint Expeditions, all in the short period of 1925-1939, while still teaching and working on the most important general problems in petrography.

The most amazing fact is that F. Yu. Loewinson-Lessing took active part in all these works instead of merely directing them. His passion for field observations and for the geologic aspect of petrography by no means cooled off with age. His last works in the Trans-Caucasus, Crimea,

and East Siberia made new contributions to the systematics of extrusives, the theory of magmatic formations, and the relationship of igneous activity to tectonics.

It should be kept in mind that field data of those years were collected by a man past his seventieth year, lame because of a fall from a horse! Indeed, the stamina of this great man was no less amazing than his personal charm and that consciousness of one's integrity and natural dignity which is the true mark of a man!

F. Yu. Loewinson-Lessing died of pneumonia, during the night of October 25, 1939. World petrography lost one of its most renowned men, and Russian petrographers lost their most respected teacher. However, death is impotent where reason reigns. Scientific ideas of Loewinson-Lessing endure and blossom forth in works of his numerous pupils and followers, both in the Soviet Union and abroad.

MAIN SCIENTIFIC PROBLEMS

Three main trends stand out in the extraordinarily diversified scientific heritage of F. Yu. Loewinson-Lessing. First is the problem of a natural classification and nomenclature of extrusive rocks, by chemical composition, or, more broadly, the chemistry of rocks, subsequently developed by A. N. Zavaritskiy as petrochemistry, a new branch of geology [14b]. Second is the problem of primeval magma, considered as a physicochemical system and as one of the most important factors modifying the structure and composition of the crust. Finally there is, in the words of F. Yu. Loewinson-Lessing, "the central problem of petrography as a whole, that of the origin of extrusive rocks and the causes of their diverse composition."

All his life, from the first article on the Jalguba variolites [21], to the last one, on the problems of magma [38], he was busy on these three cardinal problems, closely related to which are the main problems and methods of petrography, geology, tectonics, volcanology, and geophysics.

CHEMICAL COMPOSITION OF EXTRUSIVE ROCKS AND THEIR NATURAL CLASSIFICATION

> "La classification des roches éruptives doit se baser en premiere ligne sur la composition chimique..."
>
> F. Loewinson-Lessing (from his paper read before the 1897 International Geological Congress).

The invention of the polarizing microscope opened vast possibilities for petrography. From the very first works of H. Sorby [79], which opened a new world of mineral structure and composition, petrography has progressed rapidly everywhere. The enthusiasm for the new method has led to the accumulation of an immense amount of material which almost precipitated a crisis in science. As early as a quarter century after the advent of the microscope, petrography was swamped by a flood of new rock varieties often differing merely in structural details and mineral combinations. Uncontrolled by any general genetic idea, that catastrophically swollen roster of rocks was rapidly becoming a dam to progress.

Toward the turn of the century, the physiographic trend in petrography, headed by H. Rosenbusch, obviously came to a dead end where chaos and pusillanimous meticulousness reigned. Only a rational rock classification naturally following from theoretical achievements in petrography and establishing unity in diversity could obviate that crisis.

That revolutionary leap in the development of petrography finally took place with the appearance of Loewinson-Lessing's chemical classification of rocks. This historic crossroads was marked by three works, published simultaneously. The author of the first two [23, 70] was the young F. Yu. Loewinson-Lessing; of the third, H. Rosenbush [76] who was looking for a way out of the dead end of microscopic physiography.

A comparison of these momentous works from a modern point of view shows that the works of the young Russian petrographer have the advantage. F. Yu. Loewinson-Lessing did not confine himself to a differentiation of extrusive rocks by their chemical composition but attempted to set up chemical premises for a natural series of rocks. That was the embryo of his future chemical classification. In addition, he was the first to introduce the very important principle of classifying igneous rocks by their chemical composition, into supersaturated, saturated, and undersaturated; that corresponded to the familiar distinction between acid, intermediate, and basic but was related to an essentially different premise. In the new approach, extrusive rocks were assigned to this or that part of the series, not by the absolute content of silica, with an arbitrary boundary between adjacent groups, but rather by the ratio of their main components, and particularly of silica and bases.

This essential element of modern petrology was developed considerably later (although

without any reference to Loewinson-Lessing's priority) in a number of articles and then in the familiar text by S. H. Shand [77, 78].

The principle of chemical saturation, along with the H. Rosenbusch's suggestion to convert the chemical analyses to equivalent ratios, constituted the basis for the future chemical classification of extrusive rocks as well as for all subsequent mathematical treatments of chemical analyses as "magmatic formulas", "parameters", "numerical characteristics", "coefficients", etc.

The final formulation of this classification was given later on, in a paper read by F. Yu. Loewinson-Lessing before the Seventh International Geological Congress in Saint Petersburg (1897) and in his Doctoral thesis [24]. By that time the classification had become an orderly universal system, with the voluminous material on the chemical composition of extrusive rocks tied to the problems of their origin, magmatic differentiation, and rational nomenclature.

The value of these two works in the history of petrography cannot be overestimated. Although, back in 1890 F. Yu. Loewinson-Lessing and H. Rosenbusch had merely outlined the possibility of a new path of development, now they had perfected it so that from then on petrographers could not proceed in any other way. A chemical (F. Yu. Loewinson-Lessing, H. Washington, R. Daly, A. N. Zvaritskiy, etc.) and a physicochemical (J. Vogt, P. Niggli, D. S. Korzhinskiy, etc.) development became unavoidable.

Loewinson-Lessing's contribution to science was duly appreciated by the Congress. He was elected to the commission on the classification of extrusive rocks, together with outstanding petrographers of that time, and was asked to open its first meeting.

Withal, a chemical classification was not accepted unanimously. This is not surprising; there is no historic precedent for a painless transition to a new scientific trend. The accompanying necessity for breaking up conventional views always provokes more or less stubborn opposition. In this instance, the long reign of microscopic physiography had established mineral composition as the mainstay of a classification. It was only natural that it took some time to accept a trend favoring a chemical approach.

As early as the next Congress in Paris (1900), where F. Yu. Loewinson-Lessing was elected one of the Vice Presidents, his new principles met vigorous opposition from a number of participants. Among the more prominent opponents of a chemical classification were two of his countrymen, A. P. Karpinskiy

[66], and Y. S. Fedorov [44], who presented special papers on the subject. Among the foreign champions of a mineral classification was F. Fouquer, the outstanding French petrographer.

The main points of the objections were the convenience and low cost of structural mineralogic methods of studying extrusive rocks, the difficulty of judging the variations in mineral composition from chemical analyses, and the impossibility of a classified differentiation of heteromorphic facies.

In his turn, F. Yu. Loewinson-Lessing emphasized the qualitative rather than quantitative nature of mineralogic principles of classification, their limited application to semi-crystallized extrusives, and their inherent underestimation of the complexity of chemical composition in rock-forming minerals.

It should be emphasized that F. Yu. Loewinson-Lessing by no means underestimated the value of other bases for a rational classification. In the Congress, he set forth his views as follows: "The characteristic of major groups (such as families) should be based on chemical and mineral composition. Subdivisions of the second, third, and other orders should be based on specific criteria of mineral composition and structure."

Thus, the theoretical premises of F. Yu. Loewinson-Lessing are perfectly clear; a natural classification should be diversified. Those features of chemistry whose function is the mineral composition as well as the structural features of rocks should be its basis, however.

The obvious success of the chemical trend in petrography brought about a gradual change in views on the overall chemical analyses of rocks. Thus, Ye. S. Fedorov, one of the most ardent champions of the optical methods, went as far as working out a conversion of chemical analyses [43, 45], with his "chemical composition symbols" quite similar to Loewinson-Lessing's (magmatic formulas). To be sure, both these systems have now been relegated to the realm of history. Present-day petrography progressively deemphasizes the assorted "conversion systems" and shows a new tendency to look for support in primary figures of chemical analysis.[2]

Over half a century has passed since that argument on the principles of classification. Now that a new generation of petrographers is

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[2] Among Russian petrographers, D.S. Belyankin was a particularly strong advocate of abandoning "petrochemical oversimplification" [7].

free of the old tradition, and the horizons of petrography are much wider, we see clearly that both opposing camps were right. The chemical and the mineral composition of rocks are two indivisible aspects of the most important feature of the crust, the physical composition of its component rocks. Seen in that light, the argument about a "primeval basis of classification loses its meaning.

Withal, Loewinson-Lessing's ideas, rather than his opponents', were closer to those of the present. The study of the chemistry of extrusive rocks has been gaining rather than losing in importance. Now we know that fine points of chemical analysis often characterize definite rock associations as well as entire petrographic provinces. Such small fluctuations in the ratios between "principal", "secondary", and "minor" elements are too small to be reflected in the mineral composition of a rock but are readily detected by a standard chemical and spectrographic analysis and constitute valuable correlation criteria. Because of that, overall chemical analyses of rocks (especially those of extrusive origin) have by no means lost their value and will remain for a long time, if not forever, an essential study method. Their usefulness will be limited only by our better knowledge of relationship between the optical properties of rock-forming minerals and the details of their mineral composition. As things stand now, "composition-properties" diagrams are far from being perfect, and it will be some time before petrographers obtain a reliable means of arriving at the true (rather than a conditional) chemical composition of rocks from their quantitative mineral ratios.

F. Yu. Loewinson-Lessing's basis for the present chemical trend in petrography is just as important as a cornerstone of a building.

The chemistry of rocks as a basis for petrographic classification and as a criterion for designating genetic groups and the study of the evolution of magmatic processes always attracted F. Yu. Loewinson-Lessing. Having made use of the voluminous analytical material and variation statistics, he was busy for some years on the problem of natural boundaries between similar families of extrusives. The result was his well-known study of the boundaries and subdivisions between andesites [32], basalts and andesite-basalts [33], liparites and dacites [73], and basanites [35a]. The same group of works includes an article on chemicogenetic equivalence of andesite and diorite, and trachyte and syenite [37], published one year before his death.

It should be kept in mind that a chemical classification, as such, never was the goal of its author. Even in his earlier attempts [24], the classification of extrusive rocks into groups and families was just as subordinate to their chemical composition as to their origin (geologic position, differentiation, assimilation, etc.). This geologic genetic concept of a classification was modified and improved upon, with the progress of geology. Its latest variant [38], with its emphasis on the distinction between ortho-, apo-, and paramagmatic rocks, is quite different from the concept of the turn of the century. Well, the modern car is just as different from the "steam carriage" model exhibited at the 1900 World Fair in Paris!

PROBLEMS OF MAGMA

> "...Inasmuch as igneous processes are most closely related to tectonic processes, problems of magma are essentially the problems of general geology..."
> F. Yu. Loewinson-Lessing (from an outline of a 1940 work).

This thought, formulated by F. Yu. Loewinson-Lessing some 20 years ago, fully reflects the present development of geologic science, as well. What is more, the problem of magma and magmatic processes has acquired in the meantime an even greater importance insofar as its solution, in addition to its broad theoretical implications, is of practical importance, affecting as it does human lives.

The problems of magma can be approached in two ways. First, they reflect the physico-chemical aspect of petrography inasmuch as they deal with the nature of magma and with the laws of its crystallization. No less important is the geologic aspect of the origin of magma and of the conditions under which extrusive

rocks and associated ore deposits are formed out of a magma. Loewinson-Lessing's work has greatly influenced the development of each of these two trends in the study of magma.

The early attempts to understand the physico-chemical nature of the prime source of extrusive rocks, magma, go as far back as the pre-microscopic age of petrography. As early as the middle of the last century, G. Durocher in France and R. Bunsen in Germany supposed that magma should be somewhat similar to water solutions, in its properties. However, it was only at the turn of the century that this guess became a working hypothesis, supported by the weighty evidence of microscopic and experimental petrography.

J. Vogt [82] was the first to point to the relationship between the course of crystallization in a silicate slag and the ratio of its components; in other words, to solution and supersaturation phenomena. His further studies of the properties of melts were most important in the development of a physico-chemical trend in petrography.

At about the same time, A. Lagorio [69], now operating with rocks (extrusive), formulated a view of magma as a solution crystallizing under the same laws as those affecting the aqueous solution of salts.

The subsequent development of the magma-solution idea was prompted by F. Yu. Loewinson-Lessing, J. Vogt, J. Iddings, and a number of other outstanding petrographers at the turn of the century.

In his classic monograph on extrusive rocks of the Caucasus, Loewinson-Lessing [24] considered magma to be a complex solution-melt; as such it is subject to all regularities of electrolytic crystallization, including J. Gibbs' phase rule. At the same time, he emphasized the possibility of breaking up this equilibrium state as a result of the fusing of enclosing rocks (syntexis) and assimilation of material fused.

Later on he noted [28-30] some other features modifying the simple parallel between magmatic melts and liquid solutions. First, there was the high viscosity of rock-forming magma, its capacity for considerable super-cooling, and finally its high volatile content.

That cycle of ideas fully corresponds to the present concepts and anticipates the subsequent solution of certain problems, on a broader basis. For instance, regional petrography brings forth ever new evidence of the paramount importance of assimilation in petrogenesis and mineralization (D. S. Belyankin [6]); recently there has even been a tendency to overemphasize this factor (Kh. M. Abdullayev [1]).

The next problem deals with the aggregate state of magma. What are the elementary components of a silicate melt: molecules, atoms, oxides, or ions? As early as 1898; i. e., at the dawn of the physicochemical study of silicate melts, Yu. F. Loewinson-Lessing came to the conclusion that magmatic differentiation proceeded by a displacement "of complex oxides corresponding to future minerals, rather than of individual oxides". That conclusion, shared by J. Brögger [52], directly follows from the concept of magma as a solution, and precedes the ionic concept.

In our days these concepts have found adequate substantiation. Ours is not merely indirect evidence but direct experimental demonstration of the almost complete dissociation of silicate melts (O. A. Yesin [13]). Accordingly, we now call Loewinson-Lessing's "complex oxides" either complex (e. g., $[AlSi_3O_8]^{1-}$. $[Si_2O_6]^{4-}$) or simple anions and cations, whose interaction determines the mineral composition of a solid phase (V. V. Shcherbina [46]; D. S. Korzhinskiy [16]).

It should be added that almost simultaneously with the appearance of the complex oxides concept, H. Rosenbusch [76] advanced a fantastic idea from the point of view of physical chemistry, of the foyalite, gabbro, granodiorite, magmatic "nuclei", while J. Idding [65] believed that magma, as in the columns of chemical analyses, consists of elementary oxides.

Perhaps one of the most amazing examples of F. Yu. Loewinson-Lessing's scientific insight was associated with the evolution of the idea of the role of eutectics in petrogenesis. In accordance with his views of magma as a solution, supported by his early experiments at the Polytechnical Institute Laboratory, he came to accept the idea of eutectic crystallization of silicate melts. More specifically, he associated the mineral composition and structure of granites with the eutectic nature of a granite magma [27]. It is well known, that J. Vogt has contributed much to the formulation of similar views by his experimental study of slags.

However, further experiments, particularly in the Carnegie Geophysical Laboratory, have shown that eutectics is but one aspect of the relationship between the melt components. The next step of the experimenters, followed by many petrographers, was its almost complete negation. This new view of eutectics is best expressed in N. Bowen's [10] winged sentence, "When an incongruent fusing and a solid solution come in through the door, eutectics goes out the window."

In the meantime, F. Yu. Loewinson-Lessing, finding support in the entire past experience of petrography, persisted in warning against an over zealous extrapolation from experimental results and defended the value of eutectics in the crystallization of magmatic melts [31, 34].

In that, he was right! Recently we have witnessed another significant turn in the development of the theory of crystallization. In discussing the results of his new experiments, N. Bowen [51] concluded that granites are products of solidification of melts with eutectic ratios of their components! This view has now been adopted by all who accept a magmatic origin of granite.

An even more complex cycle of problems in petrography is related to the geologic aspect of the magma problem. There is generally no

unanimity of opinion in that field, and we must be content with more or less subjective interpretations of the data of regional and experimental petrography, tectonics, volcanology, geophysics, etc. Nevertheless, although the object of our study is concealed in as yet inaccessible reaches of the earth, progress in this aspect of the magmatic theory is unquestionable.

Paramount among the problems posed for science is that of the primeval magma. This cardinal problem dates back to the pre-microscope stage of petrography, and it has been discussed for over a century. It was controversial at the very beginning, with R. Bunsen and G. Durocher assuming the existence of two magmas (acid and basic), and B. Cotta, a single one (basalt). In a general form, this controversy on the mono-, bi-, or polyphyletic origin of igneous rocks still continues.

At the close of the last century, F. Yu. Loewinson-Lessing worked out in detail and supported by new demostrations the hypothesis of two magmas, granitic and basaltic, which originated during a pre-Archean stage of geologic history; i. e., simultaneously with the primary differentiation of matter in the mantle. According to this hypothesis, all extrusive rocks, beginning with the Archean, are mostly the result of a local remelting of solid crust.

Somewhat later on, R. Daly [55] revived the hypothesis of an original basalt magma as the source of all extrusive magmas. N. Bowen [49, 50] has become the strongest and most consistent advocate of these views. His orderly theory of crystallization differentiation for basalt magma, because of the specious "objectivity" of its experimental substantiation, has long entranced the petrographers. The publication of his works revived the old controversy, with N. Bowen's partisans appearing to have the best of it.

However, the wide recognition of the reaction principle as a controlling factor in crystallization differentiation of a single basalt magma did not shatter F. Yu. Loewinson-Lessing's position. To the end of his days he stoutly defended his concept of the granite and basalt magmas, countering the evidence of laboratory petrography with that of field petrography.

His arguments still maintain their vigor. First of all he stressed the fact of a great predominance (approximately equal, according to S. P. Solov'yev [41]) of acid and basic extrusive rocks on the continents; the lack of field evidence for a transition from one to the other; and clean-cut evidence of their age difference when they occur together in complex intrusive massifs and lava series.

He also pointed out repeatedly the lack of correspondence between the quantitative distribution of acid and basic rocks and those relationships which should have been present as a result of the separation of a residual eutectics. A simple calculation shows [72] that the end product of differentiation of a basalt melt should be not granite but a rock similar to syenite (trachyte), and that in an amount not over 10% of the original magma volume. Similar computations by C. Fenner [56] and F. Grout [60] gave the same results (12 and 10%, respectively). Consequently, huge granite intrusions common in folded provinces should have been accompanied by incomparably larger volumes of basic rocks, which is not the case.

Further accomplishments in the field study of complex petrographic formations led to a serious re-examination of the popular view of the universal significance of basalt magma in crystallization differentiation; the Bowen concept obviously could not cope with the totality of natural phenomena.

Following F. Yu. Loewinson-Lessing, the necessity of postulating an independent granitic or granodioritic magma was recognized by C. Fenner [56, 57], J. Vogt [83], A. Holmes [63] and many other foreign petrographers. At the same time, a new thesis of the necessary existence of still another, peridotitic magma, without which it is difficult to explain the origin of vast ultrabasic belts [2, 64, 84], was advanced.

By the end of the thirties, the discussion of primeval magmas ran out of arguments, since neither laboratory nor field petrography could contribute anything new. By that time, it became evident that a solution of this problem could be advanced only by combined efforts of allied disciplines: petrography, geophysics, geotectonics, etc.

At the same time, a brand new trend emerged in petrography and influenced its course for a long time; in addition to the theory of magmatic rock origin and the accompanying processes of palingenesis, syntexis, and assimilation, the theory of metasomatic petrogenesis developed rapidly. Born from the half-forgotten concepts of the French school of petrography (St. Clair-Deville, Ely de Beaumont, etc.) which assumed the possibility of the metasomatic transformation of sedimentary rocks to those with an "extrusive aspect", that theory was a reaction to the widely felt disappointment in the attempts to explain the origin of all extrusive rocks by the "reaction principle". The success of "metasomatists" abroad (K. Wegman, D. Reynolds, H. Backlund, H. Reed, et al) and to a smaller extent in the Soviet Union (V. I. Luchitskiy, N. G. Sudovnikov, G. M. Zaradze, et al) was thus an expression of the clearly defined crisis in the single magma concept. Further

enthusiasm for metasomatism resulted in an almost complete negation of magmatism as a factor in the formation even of basic and ultra-basic massifs, let alone the granitic ones. The basalt magma crisis became a magma crisis in general.

During the years of general re-evaluation of the theory of magmatic processes and the alleged "collapse of obsolete views", F. Yu. Loewinson-Lessing lost no time in coming out for "the defense of magma" [36]. That period can be called the crown of his creative life; it was then that the personality of this outstanding scientist was revealed at its best.

The field experience of F. Yu. Loewinson-Lessing was largely on shallow volcanic and plutonic formations, with granitization phenomena either missing or unimportant. Nevertheless, that by no means prevented him from recognizing the importance of metasomatic rock-making whose graphic examples were described by his students [4, 5].

taken from a work of A. Rittman [75], present President of the International Volcanologic Association.

Disregarding the fact that the petrographer deals here with a genetic classification of rocks while the volcanologist with that of magmas, the complete parallelism of their concepts is evident.

The main feature of these last generalizations by F. Yu. Loewinson-Lessing is the fruitful idea of "heterogenesis" in rock-making; viz., rocks of a similar type can be formed out of primary magmatic melts of a subcrustal origin as well as out of anatectic magmas, out of the fusion of magmatic melts with solid rocks of any nature; by a mixture of magmas; and finally by means of metasomatic transformations. The task of petrography, geochemistry, and geology is to find the identification criteria for these products of petrographic convergence.

The idea of heterogenesis, particularly as it

F. Yu. Loewinson-Lessing 1937-1939 Rocks	A. Rittman 1958 A. Magmas

I. Orthomagmatic
  1. Prototectites (primary magmatic)
  2. Anatectites (remolten)
 	
  3. Syntectites (products of fusion and assimilation)
II. Apomagmatic (hybrid magmatic rocks)
 	
III. Paramagmatic
  1. Migmatites
  2. Xenolites
  3. Contaminites
  4. Metasomatites
	1. Primary (or prototectic, existing since Precambrian time)
	2. Secondary (or anatectic, related to remelting of the basement)
	3. Syntectic (results of fusion and assimilation)
	4. Hybrid (results of rock mixing)
	
	B. Migmas

Of course, any naturalist is inclined to base his conclusions on his own observations. It requires a great deal of tolerance and scientific impartiality to recognize a new trend of thought at variance with one's own ideas, let alone going on from there, with the new trend.

The two last works of F. Yu. Loewinson-Lessing on the problems of magma [36, 38] present a remarkable synthesis, quite in accord with present views, despite the decades' long interval. Given above are concepts of magma, as taken from those works[3] and as

concerned the origin of granites (in terms of the problems of granites and "granites") was subsequently developed by H. Reed [74] who admitted, by the way, that "the classic theory of two magmas" is in better accord with field observations as well as with common sense. A similar approach to the magmatism-metasomatism problem as applied to rocks of "extrusive origin", is typical of many other outstanding petrographers, both at home (D. S. Belyankin [8]; G. D. Afanas'yev [3]; Yu. A. Kuznetsov [17]; V. A. Nikolayev [40]) and abroad (F. Grout [61]; A. Buddington [53]).

The fertility of this idea is well illustrated also by the present status of the volcanic-plutonic problem. In developing the R. Daly

[3]F.Yu. Loewinson-Lessing's conclusions tabulated by P.I. Lebedev [19].

theory of a single subcrustal basalt magma and the anatectic nature of post-Archean granites, W. Kennedy and E. Anderson [67] revived the old views of C. Lyell on independent volcanic and plutonic formations. This concept was now taken up by H. Reed and some other petrographers. Indeed, the independence of acid and basic rocks follows directly from the thesis of a separate origin of corresponding magmatic melts. Now, if we assume with F. Yu. Loewinson-Lessing that both basalt and granite magmas may have a prototectonic as well as an anatectonic origin, the possibility of a discrete volcanic-plutonic formation becomes inevitable.

It should be noted that recent geologic literature cites ever-new examples of a close connection between outflowing and hypabyssal intrusive rocks, especially in younger folded provinces. The regional aspect of volcanic-plutonic formations in the folded fringe of the northeastern Pacific basin was recently considered by A. Buddington [54], and of the northwestern, by Ye. K. Ustiyev [42].

Thus, F. Yu. Loewinson-Lessing's last articles were truly in advance of his time in their anticipation of present views, and the problems formulated by him are still with us.

THE ORIGIN OF EXTRUSIVE ROCKS

"The problem of the origin of extrusive rocks can be approached in two ways. First, from the composition and structure of the crust and from geophysical and geochemical data, by way of hypotheses. Second, from a concrete study of extrusive rocks and their associations and from their geologic and geographic distribution, by way of facts."
F. Yu. Loewinson-Lessing, The Problem of the Origin of Extrusive Rocks and the Ways of its Solution, 1954.

This cycle of problems is so closely related to the preceding one that a detailed consideration would entail a repetition of much of what has been said. Almost all of the over 300 published works of F. Yu. Loewinson-Lessing deal to some extent with the causes for this diversity of extrusive rocks. He attacked this problem with all accessible field and laboratory means of study. His principal conclusion is as follows: "1. The diversity of extrusive rocks and their geologic relationship are best explained by assuming the existence of two primeval magmas, acid and basic. 2. None of the differentiation theories based on a single factor, including the now favored theory of crystallization differentiation, embraces without strain the totality of differentiation processes. In addition to crystallization differentiation in its various aspects, we would have to reckon with liquation, assimilation, and certain other demonstrated or assumed differentiation factors. 3. There are three categories of igneous rocks: prototectites, anatectites, and syntectites... The deciding voice in this petrogenetic problem is the voice of geology..." (Italics by F. Yu. L.-L., [34]). Thus the idea of heterogenesis, now in vogue, was clearly formulated and substantiated over a quarter century ago.

Standing out among this large group of problems are two interrelated ones which greatly influenced the creative thinking of F. Yu. Loewinson-Lessing and the development of petrography. The first is the problem of assimilation; the second, of magmatic differentiation or liquation.

As early as his Doctoral thesis [24] F. Yu. Loewinson-Lessing considered the possible consequence of an interaction between magmatic melts and the enclosing older sedimentary rocks. He concluded that one of the results would be a fusing of rocks in the magmatic chamber walls (syntexis). An assimilation of foreign material by the magma should alter its chemical composition as well as destroy the balance of components. One of the theoretically possible results of such a chain of events would be a splitting of the new heterogeneous melt into derivative magmas of a different composition; i.e., a magmatic differentiation. Based on assimilation phenomena, this became the syntectic-liquation theory.

The very appeal to assimilation as an essential cause of petrogenesis was quite advanced for that time. It is to be noted that J. Brögger, at the same time, denied any appreciable effect of assimilation, particularly in the formation of the Oslo area extrusives [52], while N. Bowen and his followers, decades later, practically ignored the possibility of any effect of assimilation and reduced petrogenesis to a consecutively developing crystallization of a homogeneous basalt melt.

The syntectic-liquation theory of F. Yu. Loewinson-Lessing was subsequently taken up and developed by R. Daly [55] as the "assimilation-differentiation" theory. To be sure, in his later work [12], and influenced by the general scepticism with regard to pre-crystallization differentiation, he analyzed the

petrogenetic effect of assimilation, alone, and was rather wary of the existence of immiscibility phenomena in a magma. Such a position of one of the greatest petrographers of our time reflects the evolution of petrographic concepts. The loss of faith in the fact of liquation was accompanied by an ever-growing interest in syntexis and assimilation. As noted before, this led to some extreme positions.

Of particular interest is the history of the other aspect of this problem. The first published work of F. Yu. Loewinson-Lessing [21] dealt with a peculiar diabase from Jalguba (Karelia) having a groundmass similar to semi-crystalline picrite-basalt with varioles similar to vitreous andesite-dacite dispersed in it, in a drop-like "silicate emulsion". An attempt to determine the cause of a precrystallization differentiation of these phases, differing in composition and water content, led finally to a formulation of the syntectic-liquation theory, whose roots go back to old concepts of liquation by G. Durocher. Syntexis — assimilation — segregation — differentiation — this is the alleged sequence of precrystallization processes, associated with which is one of the causes for the diversity in extrusive rocks.

Subsequent observations of the Mugodzhary variolites [26] and of eutaxitic gabbros from Denezhkin Kamen [25] with their alternation of plagioclase, olivine-pyroxene, and magnetite bands, supplied new evidence of liquation. It was assumed that a precrystallization segregation had taken place under a tangential tectonic stress.

However, the strongest support for an early segregation of the components of a magmatic melt came from a discussion of the origin of anorthosite and other monomineral rocks [30, 34, 38, 72]. Indeed, the active contact phenomena at the periphery of these intrusions, as well as the presence of vein facies and of recurrent injections of a monomineral melt, ruled out the idea that these giant massifs had been formed by an intrusive "crystal gruel", as supposed by the advocates of an exclusive gravity-crystallization differentiation.

The liquation idea was favored at first by many noted petrographers (R. Daly, P. Niggli, F. Grout, H. Tyrrell, and others). Later on, however, the immiscibility clause ran into serious objections from experimental petrographers, J. Greig [59] and N. Bowen [50]. The basis of their objections was the failure of G. Greig in an experimental reproduction of liquation in a dry silicate melt. This failure discredited for a long time the idea of segregation of a silicate magma and created a strong prejudice on the part of the advocates of the reaction principle and crystalline differentiation.

In the meantime, the number of natural phenomena explicable only by liquid immiscibility or stratification of the melt kept increasing. Despite the experimental "veto", the liquation concept would not die. Besides the experimentally corroborated segregation of ore-silicate melts, agreed upon by all petrographers, new field evidence of liquation came from Europe (V. N. Lodochnikov, S. I. Tomkeyev, B. Asklund, T. Krokström [39, 47, 68, 81]) and from America (T. Tannon, T. Barth, K. Fenner [48, 57, 58, 80]). The evidence of field petrography was in direct contradiction to experimental results.

In noting that J. Greig experimented only with dry systems while all field observations suggest the effect of volatiles, primarily water, F. Yu. Loewinson-Lessing protested against these attempts to belittle the value of geologic evidence through experiments not corresponding to natural conditions. Fifty years after his first study, he came back to the problem of Jalguba variolites in one of his last works [35b] in which he restated and refined his old ideas on the liquation mechanism.

Soon after that, D. P. Grigor'yev [11] presented the first demonstration of immiscibility in a range much wider than did G. Greig, on fluorosilicate systems. That marked a swing toward acceptance of the idea of liquation in silicate magmas, by Russian petrographers. Since than, D. S Belyankin [9] deemed it impossible to deny it for aqueous silicate systems, as well; D. S. Korzhinskiy [15] recognized it, with certain reservations, for a water-bearing granite-eutectic melt; and A. P. Lebedev [20] insisted on the necessity of recognizing the liquation phenomena in traprock magmatism.

In most recent years, Z. P. Yershoya and Ya. O. Ol'shanskiy [14a], similarly working on fluorosilicate systems but with O^{2-} and F^- completely replaced, widened the immiscibility range even more, now taking in basalts, and with granitic melts at the boundary.

The encouraging results of the most recent experiments suggest that the end of this half-century old argument on the possibility of magmatic liquation is near. F. Yu. Loewinson-Lessing's conviction that geology should have a decisive voice in petrogenetic problems has the field!

Now, this argument about liquation called first of all for an enormous erudition and a clear understanding of limitations of both experimental and field methods. At the same time, it called for great courage, because there is no harder struggle than fighting a prejudice. Only a leader in science and a great man could win a victory (even if posthumous) in this long, momentous argument in the progress of petrography.

* * *

We have considered here only the main scientific interests of F. Yu. Loewinson-Lessing in the context of the general development of petrography. However, as repeatedly emphasized before, the scope of his creative activity was much larger and impossible to cover in one article on a single subject. A special place should be given to the analysis of his works on magmatic mineralization, on the relationship of tectonics and igneous activity, and on regional, applied, and experimental petrography. The extraordinary diversity of his scientific heritage is graphic evidence of his constant striving for a comprehensive view of the petrogenetic process. This most important aspect of the scientific views and creative methods of F. Yu. Loewinson-Lessing has been an inspiration to his pupils in their comprehensive approach to basic problems of petrogenesis, based first of all on geology. Therein lies the stimulus for a further development of ideas of this leader of Russian science and one of the poineers of modern petrography.

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STRUCTURE OF THE EARTH'S CRUST
AND SOME PROBLEMS IN PETROGRAPHY[1,2]

by

G. D. Afanas'yev

This issue marks a significant date, the 100th anniversary of the birth of one of the greatest petrographers, F. Yu. Loewinson-Lessing.

The wide range of his scientific interests also included the structure of the earth, a problem, closely related to such scientific trends developed by him, as the theory of formations and primeval magmas.

The problem of regular associations of extrusive rocks, magmatic complexes and formations, is quite essential in our attempts to determine the structure and evolution of the crust. This topic will be considered in more detail in the concluding part of this work.

F. Yu. Loewinson-Lessing realized quite clearly the importance of studying the deep structure of the crust in solving petrographic problems. As early as 1915, in connection with a practical problem on "Pressure in Tunnels", he considered such subjects as "rock pressure" and rock plasticity at depths. He critically evaluated the data of L. Adams and Heim, along with their implications, in so far as they pertained to the building of tunnels.

Turning to theoretical problems of petrography in his last years, F. Yu. Loewinson-Lessing considered some topics which now have become current scientific problems in his article "The Origin of Igneous Rocks". While on the subject of primeval magmas, for instance, he discusses the L. Fermore and P. Eskola concepts that a potentially basaltic magma should be present as eclogite, the most dense mineral association. The present article deals largely with recent studies by J. Lovering

in support of an eclogite composition of the upper mantle.

Concepts of the vitreous state of deep-seated basalt magma, based on seismic data of that time (1934-1953), brought some doubt to F. Yu. Loewinson-Lessing. The views of E. Suess and R. Daly on the structure of the earth (sial, sima, etc.) he believed to be hardly relevant as far as the problem of petrogenesis was concerned. He wrote, "We are interested primarily in the upper 100 to 120 km, and often in a few tens of kilometers or even in the uppermost ten kilometers, because it is there that intrusion takes place".

The best illustration of his great interest in the deep structure of the crust and of his grasp of the new methods of study is his letter to the Institute of Theoretical Physics (Figure 1) in which he points out the necessity for studying the deep crustal structure by geophysical methods, beginning in 1938.

PETROGRAPHIC COMPOSITION OF THE CRUST IN THE MOHOROVICIC DISCONTINUITY ZONE

Petrographic interpretation of geophysical data was considered in my paper read before the session of the division of Geological and Geographic Sciences, the U. S. S. R. Academy of Sciences, February 1960 (see Izvestiya Akad. Nauk, U. S. S. R., Geological Series, no. 7, 1960). The majority of geophysicists and geochemists believe that the Mohorovicic discontinuity represents a boundary between the crust and the mantle; i. e., between two envelopes substantially differing in constitution.

Numerous geophysical studies indicate that the Mohorovicic discontinuity is at 40 km below the continents and 6 km below the deepest oceanic bottom. Thus, we deal here with a thin film, compared with radius of the earth: 0. 6% of the latter in the continents and 0. 01% under the oceans.

This upper "film" of the earth is most

(English translation)

To the Institute of Theoretical Geophysics

Several years ago, at the suggestion of Prof. K.I. Preobrazhenskiy, I brought up the subject of a special commission for studying the deep structure of the crust, with geophysical methods. The most rational methods of such a study (electrodrilling) as well as those most promising scientifically and practically were outlined in several conferences. The status of the Commission for Geophysical Study of the Crust, at the Division of Mathematical and Natural Sciences (OMEN) was worked out at the same time. The scientific and practical importance of a deep study of the earth's crust (beginning with 5 to 10 km and down to 100 or 200 km) cannot be overestimated. However, for a number of reasons, this important scientific project has not been realized. At a recent conference in Leningrad, it was decided to take up this project again and, if possible, to get it going in 1938. The conference, with Academician Loewinson-Lessing, Professors Krayev, Petrovskiy, and Ryabko, and several other scientists, resolved to address itself to the Institute of Theoretical Geophysics, as the most authoritative organization in this field, with a petition to include the deep study of the earth's crust in its 1938 work program. The 1938 cost has been estimated at about 200,000 to 300,000 rubles, as presented in the enclosed schedule. A detailed budget will be worked out after an affirmative decision, in principle. Considering that all members of this conference, who at the same time are prospective participants in the project, live in Leningrad, it would be advisable to have also the participation of the Earth Crust Institute at the Leningrad State University.

Acad. F. Loewinson-Lessing

FIGURE 1. Letter from Academician F.Yu. Loewinson-Lessing to the Institute of Theoretical Physics on setting up a geophysical study of deep crustal structure.

important because it is there that various geologic processes take place and it is the only source, for the time being, of most valuable minerals which determine to a considerable extent our technical and cultural progress.

One of the most important results of geologic study of the earth's surface is that it demonstrates the feasibility of a direct study of objects originating at depths and exposed by tectonic (or, more generally speaking, magmatic) processes.

Such results of study as geologic, tectonic, and other maps, as well as theories on the evolution of geosynclines, magmatic differentiation and magmatic associations of cognate rocks; parageneses of elements, minerals, and rocks,

all contribute to a more or less objective concept of the structure of the crust and of its development in the continents, during the life of the earth as a planet.

When it comes to the oceanic segments, geologic knowledge consists of fragmentary data on the structure of oceanic islands, bottom sediments, and bottom relief. In the last 20 or 25 years considerable geophysical information has been accumulated on the propagation velocity of seismic waves and on gravity anomalies in various segments of the crust. By its very nature, such information has indirect value. Our judgment on the continental crust is immeasurably better substantiated than on the oceanic crust.

As a result of geophysical studies of elastic waves caused by special explosions, and of seismic waves caused by earthquakes, as well as of gravity anomalies, there is no longer any doubt that the velocity of elastic waves changes with depth, in a manner different for different segments of the crust (continental and oceanic).

The Mohorovicic discontinuity surface is present everywhere and is marked by a certain jump in the rate of change of velocity V, from 7 to 8 km/sec. It has been determined that under the present continents this discontinuity surface lies at average depths of 40 km, and in deep reaches of the oceans, at about 10 km, including about 5 km of water. A detailed survey of literature on the structure of the crust has been made before [5].

According to many students, the oceanic crust is a layer of basic rocks with a velocity of 6.4 to 6.9 km. It is overlain by less than 1 km of consolidated to semiconsolidated sediments and underlain presumably by the mantle with a peridotite or perhaps eclogite composition.

In his report on the structure of the crust of the western Pacific, from the study of seismic waves of nuclear explosions in the Bikini and Eniwetok areas, D. S. Carder [23] points out that the Mohorovicic discontinuity occurs here at about a depth of 18 km and that the crustal structure under those islands is similar to continental structure.

All geophysicists have noted a certain relationship between the structure of the crust, and the depth of the basins above individual structures M. Ewing and F. Press state that "It has been established without any exception that everywhere under large areas of water less than 1000 fathoms (1820 m) deep, the crust is typically continental; it is typically oceanic under more than 2000 fathoms of water (3460 m)".

The recently identified intermediate type of crust, characterized by a shallower occurrence of the Mohorovicic discontinuity and consequently by a thinner crust of 18 to 20 km, has been observed in oceanic shelves and in seas 2000 to 3000 m deep (Mediterranean, Black, etc.).

Recent seismic data from the Atlantic bottom emphasize even more the relationship between the oceanic depth and changes in the crustal structure. Depending on the bottom relief, as shown by J. and M. Ewing [22], the oceanic-type crust is distributed under the Atlantic in haphazard spots.

An interpretation of geophysical data reveals the inadequacy of experimental studies of elastic waves in their passage through different natural media at different pressures and temperatures. In the Atlantic, the Mohorovicic surface was often identified by an increase in velocity merely approaching 8 km/sec [7-9], although in experiments with peridotite rocks, even at normal pressures and temperatures, the velocities obtained were over 8 km/sec.

In their paper for the Twenty-First Session of the International Geological Congress, "Results of Seismic and Sonic Studies of the Structure of the Crust in Seas and Oceans" [14], Yu. I Neprochnov, A. P. Lisitsin, G. B. Udintsev, et al, cite the latest data on the structure of the crust under the Black and Japanese Seas.

In the Black Sea, the over-all thickness of the crust is 22 to 30 km. The "basalt" layer with V = 6.4 to 6.8 km/sec is 10 to 18 km thick. It is overlain by 7 to 14 km of sedimentary rocks.

In the Sea of Japan, the Mohorovicic surface is about 12 km deep. At that depth, the velocity of elastic waves is 8 km/sec. Above that there is a "basalt" layer, about 7 km thick, with V = 6.2 to 6.4 km/sec, and a water column of about 4 km.

Why, under such conditions, a 6.2 to 6.4 km/sec layer should be designated as "basalt" is not clear; geophysical and experimental material on hand (Yu. V. Riznichenko and many other authors) suggest that the velocity of elastic waves in a "granite" layer of the crust may approach 6.4 km/sec.

In any event, the above-mentioned relationship between a "reduced" crustal thickness in the seas and oceans and the greater depth of the corresponding basin is unquestionable. The causes of this phenomenon have no well-substantiated explanation, except for the speculations by some geologists on a partial to complete destruction of the granite layer, in a geologically short time interval, by activity of the underlying basalt substratum.

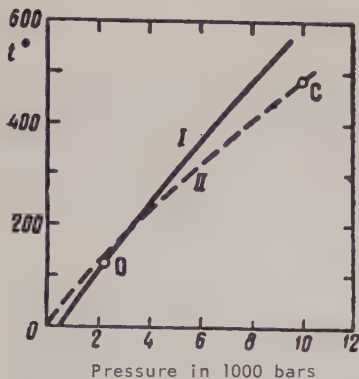I have already discussed [3-5] the small

FIGURE 2. Pressure and temperature
distribution under the ocean (I)
and the continent (II); after J. Lovering.

probability of only 6 to 7 km of a "basalt" crust
separating the ocean bottom from a peridotite
mantle. The specific objections are as follows:

a) experimental studies by D. Hughes and J.
Cross [26] have shown that at such tempera-
tures and pressures the velocity of elastic
waves in dunites exceeds 8.8 km/sec, rather
than fluctuating in the vicinity of 8 km/sec, as
specified for the medium below the Mohorovicic
discontinuity;

b) the equivalence of heat radiation under the
continents and the oceans, approximately 1.2 x
10^{-6} cal/cm^2/sec, suggests that the over-all
amount of radioactive substances in the crust,
at depths of 150 to 200 km, is about the same.
This is pertinent only if the heat flow in the
earth is determined chiefly by radioactive ele-
ments distributed in its upper reaches (down to
200 or 300 km, according to Slichter);

c) among terrestrial rocks, dunite is known
to possess the lowest radioactivity, with a total
U + Th content of 0.06 x 10^{-4}% (according to F.
Birch).

All that, in addition to geologic facts, casts
a doubt on the occurrence of a peridotite mantle
at depths of only 6 to 7 km below deep oceanic
bottoms.

In 1958, J. Lovering published a paper in
which he demonstrated that the eclogite compo-
sition of the upper crust is in accord with new
data on the composition of meteorites (eucritic
achondrites) and on the physical properties of
the upper mantle. According to him the Mo-
horovicic discontinuity represents a phase
transition from low pressure basalts (gabbro)
to high pressure eclogite.

The eclogite composition of the upper mantle
appears to do away with the contradiction
emerging from the distribution of radioactive

elements. By the same token, an oceanic crust
is more readily formed by the differentiation of
an eclogite mantle (i.e., containing alumina and
alkalies) than of a dunite and peridotite one.

Some geophysicists and tectonists have used
this hypothesis as a basis for momentous con-
clusions. For instance, V.V. Belousov [6] in-
ferred a "basalt stage" in the evolution of the
earth, and a "basalt flood" at the close of the
Paleozoic and the onset of the Mesozoic, be-
coming particularly intensive in the Neogene.

According to him, during the Mesozoic, there
occurred mass flows of plateau basalts; a ba-
saltization of grabens of the Red Sea type; and
the formation of mediterranean seas and
oceans, occasioned by collapse of the "granite"
crust, and its replacement by basalts.

For V.A. Magnitskiy [16], the equivalence
of heat flows means a negation of mobilism (i.e.,
lateral shift of crustal blocks for thousands of
kilometers). He recognizes two types of crust
and agrees with J. Lovering on an eclogite com-
position of the mantle.

Because of many of these hypotheses on the
composition of the mantle and on the differences
in the crusts in continental and oceanic provinces
are followed by cardinal geologic and petrologic
conclusions, it is wise to supplement what I have
said on the peridotitic composition of the oceanic
"mantle" by an analysis of facts supporting the
concept of a peridotite composition of the upper
mantle.

We geologists are interested primarily in
assumptions of cardinal differences in the struc-
ture of the uppermost envelope of the earth,
specifically, whether the Mohorovicic discon-
tinuity has been caused by petrographic differ-
ences between the crustal rocks and those in the
upper mantle; also whether the crust under the
present continents, oceans, and mediterranean
seas is truly different in its thickness and com-
position.

According to J. Lovering, the Mohorovicic
discontinuity under the oceans is characterized
by a temperature of about 123°C and a pressure
of about 2200 bars; the corresponding figures
for the continents are ±480°C and 10,000 bars.
According to Lovering, phase transformations
from basalt to eclogite are possible under such
conditions, which leads to a jump in density and
consequently in the velocity of elastic waves.
His premise is that basalts (gabbros) and eclo-
gites are isochemical formations whose change
of state is determined solely by optimum com-
binations of temperatures and pressure, on the
whole without any addition of new material. He
comes up with two points (Figure 3) on a curve
determining an equilibrium field for the phase
change from basalt to eclogite, as a function of
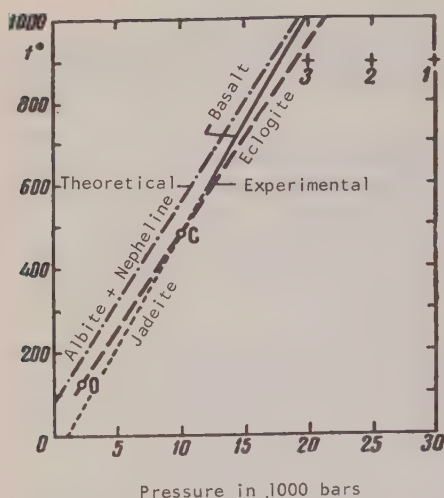temperature and pressure.

FIGURE 3. Calculated pressure-temperature
curve for basalt ⇄ eclogite transformation,
correlative with the theoretical (after
Kelly et al, 1953) and experimental (after
Robertson et al, 1957) equilibrium curves
for the reaction albite + nepheline → 2 jadeite
(after J. Lovering).

However, it becomes clear from the text
and from Figure 3 that if at point C (of the
Mohorovicic discontinuity at 35 km under the
continents) the computed temperature and
pressure (t = 480°C; P = 10,000 bars) approach
the transformation condition Ab + Ne → 2 jadeite,
experimentally observed, the results obtained
for point O (Mohorovicic discontinuity under the
ocean, with P = 2200 bars and t = 123°C) turned
out to be quite surprising for J. Lovering him-
self: the temperature was too low. He gets
around that difficulty by arguing that a change
from basalt to eclogite, under such conditions,
is possible in the course of a long time, geo-
logically speaking.

In connection with the curve in Figure 3, it
should be noted that extrapolation of an experi-
mentally and theoretically determined passage
point, albite + nepheline → 2 jadeite, with para-
meters t° ~ 600°C and P ~ 12,000 bars, to
points O and C with the respective parameters
t ~ 123°C, P ~ 2200 bars; and t° ~ 480°, P ~
10,000 bars, cannot be taken as a basis for as-
suming the basalt-eclogite change at points O
and C (Mohorovicic discontinuity under the
ocean and the continents, respectively).

The principal mineral phases of eclogite are
1) pyroxene — omphacite whose Na-component,
jadeite, appears to form, in various proportions,
solid solutions with the other component —
diopside. What the parameters t° and P are in
the forming of omphacite with a different con-
tent of the jadeite molecule remains unknown;
2) the specific garnet of eclogites in the same

diagram (Figure 3) is formed at temperatures
and pressures much higher than parameters t°
and P for which the change Ab + Ne → 2 jadeite
has been experimentally demonstrated. Assum-
ing, in accordance with experimental data, that
the Mohorovicic discontinuity under the ocean
corresponds to the change basalt ⇄ eclogite, we
should anticipate that temperatures required
for that reaction would warm up the oceanic
water. This has not been observed.

Identification of the substance below the
Mohorovicic discontinuity as eclogite runs
contrary to the velocity of longitudinal waves
(about 8 km/sec), which are too low for the
high density of eclogite (specific weight 3.5).

From experimental data of D. Hughes and J.
Cross [26], the velocity of elastic waves in
dunite (density 3.16) is 8.60 km/hr, at t = 20°C
and P = 70 bars; and 8.89 km/sec at t° = 100°C
and P = 2500 bars; i.e., under the Mohorovicic
discontinuity conditions as determined by J.
Lovering.

Naturally, a much greater velocity increase
should be anticipated for eclogite, which is of a
much greater density under surface conditions
(specific gravity up to 3.6), at a pressure of
2200 bars, than for dunite with a specific gravity
of 3.16, under surface conditions.

In the absence of experimental data, it is of
course impossible to assign any other velocity
of elastic waves for eclogites at different
pressures and temperatures, but it must be
higher, under natural conditions, than for dunite
with a specific gravity of 3.16.

H. Kuno [25], on the basis of his study of
inclusions in Japanese and Hawaiian lavas,
argues that the Mohorovicic discontinuity is the
boundary between a gabbro layer and the
peridotite substratum.

Eclogites are fairly rare rocks and com-
paratively little known, geologically and petro-
graphically. Tables 1 and 2 present chemical
analyses and the radioactive-element content in
basalts, eclogites, and dunites, after J. Lover-
ing [27]. A comparison of these figures does
not necessarily reveal identity in composition
between eclogite and basalt, let alone eclogite
and eucritic achondrites. This is especially
true for alkalies and water; the latter is omitted
in Lovering's analyses.

Eclogites described from Central Europe,
California, and the Urals, are quite different
in composition; they are generally associated
genetically with the transformation of ultra-
basites, which takes place at the addition of a
new substance.

Specifically, G. Switzer, [32], in considering
the origin of California eclogites, points out that

20

Table 1

The Content of Radioactive Elements in Basic Rocks;
after J. Lovering

Rock	U		Th		K	
	ʙ %	source	ʙ %	source	ʙ %	source
Basalt, intermediate	$0.6 \cdot 10^{-4}$	Birch	3.2^{-10-4}	Jacobson	0.9	Birch
Eclogite from diamond vents, South Africa; average	$0.5 \cdot 10^{-4}$	Holmes	$1.3 \cdot 10^{-4}$	Holmes	0.6	—
Dunite, Twin Sister; average	$0.015 \cdot 10^{-4}$	Birch	0.046	Jacobson	0.001	—
Eucritic achondrites	$0.2 \cdot 10^{-4}$	Patterson	$0.07 \cdot 10^{-4}$	Patterson	0.047	Edward

Table 2

Average Composition of Eclogites, Olivine Basalts, Norites,
and Eucritic Achondrites; after J. Lovering

Components	Eclogites (34 analyses)	Olivine basalts (116 analyses)	Norites (Bushveld Sudbury, etc.)	Eucritic achondrites (25 analyses)
SiO_2	49.2	48.93	49.83	49.87
Al_2O_3	14.6	15.69	18.08	12.00
FeO*	12.6	11.96	9.37	16.73
MgO	8.9	8.24	9.00	10.12
CaO	11.5	11.31	11.82	10.65
Na_2O	2.5	2.80	1.75	0.55
K_2O	0.7	1.07	0.15	0.08
Total	100.0	100.0	100.0	100.0

*Fe_2O_3 converted to FeO. All analyses are reduced to 100.0.

glaucophane schists and associated eclogites have been formed at intermediate temperatures and pressures, as a result of contact-metasomatic metamorphism.

Kas. Smulikowski [31], who studied east Sudetan eclogites, belives that they had been formed not because of any particularly high pressures (according to P. Eskola), but because of granitization of a schist complex containing interlayered ultrabasic bodies, not necessarily at high pressures. In his particular study, he rejects chemical metamophism of basic rocks according to Grubenmann-Becke and he believes that the formation of eclogites is a kinetic process as well as a static one.

P. Hahn-Weinheimer [24] and R. Marshall, who on different occasions studied the geochemistry of the Fichtelgebirge eclogite massifs (lead isotopes, R. Marshall; carbon and rare elements, Hahn-Weinheimer), are inclined to regard these eclogites as metamorphosed (reworked) carbonate rocks in schists.

In any event, recent investigators, unlike P. Eskola, are inclined to believe, and on fairly convincing evidence, that eclogites are metamorphic rocks formed out of ultrabasics, gabbroids, or carbonate rocks, either regionally metamorphosed or affected by granite intrusions.

Eclogites usually occur in small bodies and lenses among amphibolites, ultrabasites, and crystalline schists; their enclosing rocks, in

their mineral associations, belong to inter-
mediate stages of metamorphism (glaucophane,
amphibolite, etc.).

Interesting material on eclogites from the
Polar Urals has been collected and studied to a
considerable extent by N. G. Udovkina. This
material shows that the typical Polar Uralian
eclogites are metamorphic rocks, having been
formed largely out of peridotites by the action
of derivatives of a granite magma rich in
alumina and alkali (Na).

In addition, a study of the most ancient rocks
from other regions, namely the Caucasus, in-
cluding garnet amphibolites, zoisitites, and
other metamorphic rocks, also indicates that
eclogites occur in metamorphic series of inter-
mediate depths, with intrusions of Na-grani-
toids typical of geosynclinal complexes and
carrying ultrabasic rocks as an essential com-
ponent.

Thus, eclogites familiar to us are undoubtedly
metamorphic rocks, a product of rocks varying
in composition from ultrabasics to possibly
metasedimentary marbles, having been formed
at intermediate depths, through the action of
Na-granite intrusions.

In their concentration of radioactive ele-
ments, they differ little from gabbroids and
ultrabasites; consequently, they are not com-
parable, in that respect, to granitoids which
are carriers of the bulk of the radioactive ele-
ments in the uppermost crust.

What has been said on the origin of eclogites,
their physical properties (specific gravity
3.5), and radioactivity militates against ac-
cepting a universal replacement of the "basalt"
layer by rocks similar to our eclogites, below
the Mohorovicic discontinuity, and against
using that phenomenon to explain the distri-
bution of the upper mantle (down to about 200
km, in any event), as well as for the differ-
ence in the depth of the Mohorovicic discontinu-
ity, 35 to 40 km under the continents and 5 to 6
km below the ocean bottom.

Thus, we have at our disposal only indirect
evidence of elastic waves changing their
velocity with depth, bearing on the structure
of the crust and the upper mantle. There is
no direct evidence bearing on that and the
composition of those parts.

A definite answer would be the drilling of a
deep test hole in the ocean bottom, where the
crust is presumably thin, being represented by
the lower "basalt" layer. Such drilling is
actually planned in the U.S. My personal
opinion is that, technical difficulties apart, such
a project will not bring substantial results; with
the diversity of the crust and its mosaic

arrangement, a 5 to 6 km section so drilled can
hardly be generalized for the entire ocean
bottom.

It would be more expedient to drill a number
of control tests in continental areas with dis-
continuities marked by an appreciable velocity
change for longitudinal waves. Such discon-
tinuities, at comparatively shallow depths of
6 to 7 km, are known in the Ukrainian and
Baltic shields. Data on the latter are cited in
the work by Yu. N. Grachev, M. Ya. Dekhnich,
et al [7].

A study of those sections would explain why
the steeply dipping folded metamorphic and
crystalline rocks appear to be horizontally
stratified in different velocity zones about 5 km
thick. Is it because of a vertical change in the
petrographic composition of these "layers" or
merely because of a change in the density, in
connection with the ever-growing overburden?

A study of actual geologic conditions in these
zones of velocity changes will cast light on such
velocity changes in deeper zones, including the
Mohorovicic discontinuity. Particularly inter-
esting are the Baltic shield crystallines, with
rocks up to 3 billion years old, the oldest
known in the U.S.S.R.; eclogite-drusite rocks
developed here are almost 2 billion years old.
It must be emphasized, however, that the dis-
tance to the Mohorovicic discontinuity here re-
mains 40 km. The continental crust is just as
thick in the areas of younger folded structures,
such as the Caucasus. It is hardly probable
that in the Baltic shield province where, accord-
ing to N. G. Sudovikov, the roots of folded
structures are exposed, the position of the
Mohorovicic discontinuity has been stabilized
for the last two billion years!

In the light of these and previously published
data [5] it is reasonable to assume that the
8.0 ± 0.1 km/sec velocities of elastic waves
observed in the top of the so-called mantle, in
oceanic provinces, correspond to a more rapid
change in physical properties of crustal mate-
rial which, unlike the continental, has been sub-
jected to pressures of over 1000 kgm/cm^2, for
many millions of years. In some areas of the
ocean bottom, mass flows of basalt may account
for the "basalt" layer.

The earth's crust; i.e., a zone of active
endogenetic geologic processes, mosaic in
structure, and consisting on the whole of sili-
cate rocks, persists downward for no less than
60 to 70 km (geophysical data for some moun-
tain ranges). This interval is not likely to be
horizontally stratified in "granite" and "basic"
layers and is not likely to be substantially dif-
ferent in physical composition, in both the con-
tinental and oceanic provinces.

FUTURE TRENDS OF STUDY

Deep drilling presents the best means for solving this problem; it will have to be carried out in the study of known discontinuities in the platform crust, for example in the Baltic shield. However, there are other fields of study to be explored.

A correct interpretation of geophysical data requires extensive experimental studies of the entire range of extrusive and metamorphic rocks from provinces which are being studied geophysically. Experiments should be done on rocks previously studied geologically, petrographically, and mineralogically. Such experiments should supply us with physical parameters for specific rocks: their elastic properties, strength, and porosity, at different temperatures and pressures. It is extremely important to expand the experimental study of elastic waves in various rocks at different pressures, and under conditions of water saturation.

One of the most momentous problems in petrography, closely related to the structure and development of the crust, is the study of the distribution in space and time, of orderly associations of extrusive rocks, complexes and formations, often considered as provinces, in foreign literature.

As early as the eighties of the last century, F. Yu. Loewinson-Lessing, with the intuition of a true scientist, perceived the importance of considering extrusive rocks as definite associations, and laid the foundation for their study in his analysis of the Olonetsk diabase formation. He believed that the study of such specific formations prepared the ground for a genetic classification, not of magmas alone, but of rocks as geologic units [11]. He emphasized that formations were not fortuitous associations and that their study will provide a firm base of specific data for a theory of differentiation ([10, 11] page 271).

At the same time, in arguing against such assumptions as the Atlantic and Pacific provinces based on the apparent predominance of certain rock in certain areas, he pointed out that a correlation of rocks of different ages may lead to erroneous conclusions.

We note here that F. Yu. Loewinson-Lessing, in his study of specific formations (such as the Olonetsk diabase) and in designating the formations as types, such as diabase, granite, gabbro-peridotite-pyroxenite, etc., meant associations characterized by common features (composition, conditions of occurrence, origin, etc.) and represented by numerous natural examples differing only in details.

On the basis of my 1948-1950 work in the Caucasus, I have made up my mind about igneous complexes formed during a long period (on the order of 100 to 150 million years) in the evolution of deep magmatic centers. This expanded concept embraces a number of petrographic formations as understood by F. Yu. Loewinson-Lessing. For example, the Urushten igneous complex consists of a number of formations: diabase-spilite-keratophyre, ultrabasics, and plagiogranite, with their derivatives. The development of these formations is associated with a definite and long stage of development of the Caucasian folded province. I believe this approach in understanding extrusive rocks as individual formations and series is the most promising geologic approach to petrogenesis and the structure of the crust.

The present works on petrographic formations and provinces contain certain premises which require refinement. Yu. A. Kuznetsov has a number of works on igneous formations. His views are those of N. S. Shatskiy and N. P. Kheraskov; viz, that a "formation is an association of rocks closely related paragenetically." I do not believe that the term, "paragenesis", means here a mere simultaneous occurrence. Its true connotation is a community of origin, a "genetic affinity" of individual members of a formation.

A formation can be considered in two ways, as follows [8, 9]:

1. As a specific association of rocks, existing at a certain time and in a certain place.

2. As an abstract notion, a formation type including the most typical and consistent features of many specific cognate formations.

I believe that the second interpretation, not based on a great number of specific and orderly associations of extrusive rocks, does not provide a key to petrogenesis. In speaking of abstract formations, granite and diabase, F. Yu. Loewinson-Lessing meant primarily the primeval magma of a definite composition.

The leading criterion of Yu. A. Kuznetsov's classification of igneous formations is the structure of individual segments of the present earth's surface. Igneous formations associated with them are often noncontemporaneous, having originated under quite different geologic conditions. For example, a young traprock formation and the Precambrian labradorite Rapakiwi association are assigned to the platform group.

It has not been taken into account, in designating the young oceanic olivine-basalt formation, that it usually includes such rocks as trachytes and phonolites. On the other hand, as pointed out by Yu. A. Kuznetsov himself, platform alkalic rocks are quite similar to that formation and probably represent its continental

facies. Yu. A. Kuznetsov makes similar reservations for the basalt-trachyte formation of intermontane troughs.

The separate group of granitoid batholithic formations is excluded from the basic classification criterion of major structures, thus exposing a shortcoming or perhaps a lack of reliability in that criterion. The main difference between these formations is their physical composition and the origin of their component groups. More specifically, the processes of magmatic or some other differentiation as well as contact-metasomatic or other post-magmatic processes taking place under various conditions of temperature and pressure are essential in the formation of rock varieties different in type but similar in composition, as are the effects of the surrounding medium.

To be sure, the tectonic environment and igneous activity are endogenetically inseparable but the critical factor in the make up of a magmatic formation is the original magma out of which specific associations of extrusive rocks are formed under the given geologic conditions.

We are interested in determining the relationship between the Siberian traprocks and the Khatanga River basin ultrabasic and alkalic formations. For instance, what is the difference between the Uralian, Tuva, and Kola Peninsula alkalic rocks, the Tertiary alkalic rocks of Armenia (folded province), and the platform alkalic rock formations? It appears that a correct answer, essential in determining the rock and ore origin, will be arrived at in a roundabout way, through a study of specific formations, always keeping in mind that their component rocks do not merely coexist but represent an association of rocks "related" to each other.

Without intending to go into the subject of igneous formations as a whole, I am mentioning it merely to emphasize the importance of a genetic formation approach to associations of extrusive rocks in studying the deep structure of the crust.

The importance of such an approach is graphically illustrated by the attention given it at the Twenty-First Session of the International Geological Congress. A. Simonen's detailed study of petrographic provinces of Svekofenninan plutonic rocks of Finland [30] has led him to certain important conclusions, some of them controversial.

In differentiating the four magmatic provinces, strictly speaking, the granodiorite, trondjemite, charnokite, and granite, he does not adequately demonstrate, geologically, that ultrabasics and granodiorites of the fourth (granite) formation indeed constitute a province separate from the granodiorite (first) which also includes both granodiorites and ultrabasics. The presence in the same province, of microcline granites and ultrabasics, as rocks formed at about the same time is rather improbable.

The A. F. Eardley paper [21] considers the extrusive and tectonic provinces of the western states of the U. S. [21]. That author has succeeded in demonstrating the evolution of tectonic structures and the development of the centers of primeval magma in their historical aspect. A work of this kind is undoubtedly interesting and important in connection with the structure of the crust. Unfortunately, the author cites very few data on the true sequence of his rock series and on their age.

What has been said should be enough to demonstrate the importance of a detailed study of individual magmatic formations, by all available means, in order to recreate the history of magmatism for specific tectonic units. A comparative analysis of such a study will provide a basis in fact for our judgment on the deep structure of the crust and on primeval magma.

The concepts of a single primeval magma (either basalt proper or derivative of a peridotite magma) or of two such magmas (basic and acid, according to F. Yu. Loewinson-Lessing) are closely related to the structure of the crust and to its differentiation into envelopes; also to the study of noncontemporaneous igneous formations and series (magmatic complexes) formed in different geologic environments.

A study of associations of extrusive and metamorphic rocks, originating at the greatest depth, or the oldest, corresponding to a comparatively early stage of crustal development is essential in determining the deep structure of the crust and of the mantle. Petrographers should pay particular attention to those rocks, including intrusions of ultrabasic and gabbroid rocks; a detailed study of the accompanying metamorphics — eclogites, drusites, and other similar rocks — is also important.

A geochemical study of noncontemporaneous igneous complexes, primarily with respect to the concentration of radioactive elements in component members, is of great importance in gaining knowledge of regularities in the development and structure of the crust.

Ordinarily we use average values, the Clarke indexes for U, Th, K, and Rb. However, in studying regularities in the development of magmatic phenomena and the formation of the crust, it is extremely important to study the noncontemporaneous intrusions, constituents of genetically different complexes formed under different conditions (deep-seated, hypabyssal, subvolcanic, etc.) and their derivatives. For instance, the current detailed studies of

radioactive rocks from noncontemporaneous igneous complexes of the Northern Caucasus are outlining the specific feature of non-contemporaneous and diverse igneous complexes.

Series with ultrabasics are characterized by thorium-type radioactivity and by a sodium alkalinity of its acid members. Similar U/Th and K/Na ratios characterize the eclogite types of metamorphic rocks associated with ultra-basics and Na-granites in geosynclinal extrusive series.

The constant coincidence of regional zones and associations including the ultrabasic, diabase-keratophyre-plagiogranite facies occurring in a substratum of strongly meta-morphosed rocks amphibolite, garnet amphi-bolite, eclogite, etc.) suggests rather the composition of deeper reaches of the crust. The level of these deep-seated discontinuities, probably determined by the primary differentia-tion of the earth's substance, is unknown as yet, but is probably on the order of a few hundred kilometers.

SUMMARY

This and earlier expositions of geophysical data on the structure of the crust emphasize once more the achievements of geophysics in studying the differences in the physical state of various segments of the crust. However, it must be reiterated that the present status of knowledge renders controversial all attempts to identify these differences with the petro-graphic composition of crustal rocks. Sim-ilarly premature are attempts to use that identification for recreating the geologic and petrographic processes affecting the earth since the formation of the crust and up to the present time.

The works of most geophysicists usually emphasize the fact that the so-called "layers" of the crust, marked by different velocities of elastic waves, are not to be correlated with differences in actual petrographic composition; it is to be hoped, therefore, that the arbitrary terms, "granite", "basalt", "peridotite", and "eclogite" layers will not be interpreted literally and will not be used as such in a hypothesis on the evolution of the earth.[3]

The knowlege of the deep structure of the crust and its physical composition as well as the laws of its development, including the

origin or ores, is the most important task of modern geology. This is a complex problem, to be solved only by joint efforts of geologists, petrologists, and geophysicists, and assisted by a comprehensive program of experimental study and drilling of special test holes to the maximum depth attainable, at points selected in areas under study. The possible directions of such studies have been considered in this article and partly formulated in an earlier one [5].

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TECTONICS AND MAGMATIC PHENOMENA[1]

by

A. V. Peyve

"The decisive voice in a petrographic problem is
that of geology."
D. Yu. Loewinson-Lessing, 1934.

F. Yu. Loewinson-Lessing, long a leader in
petrography, addressed himself successfully
and on many occasions to the relation between
tectonic and magmatic phenomena [17-19].
That was a quarter of a century ago. In the
meantime, new facts have become known, new
theories developed, and connections, as yet un-
explained, have been perceived between tec-
tonics and magmatic phenomena. Despite the
countless multitude of works on this subject,
the author has decided to publish this article,
because some of the facts revealed by tectonics
in the last 10 to 20 years have not yet been
analyzed theoretically by the petrographers.

The problem of the connection between tec-
tonics and igneous activity is a tough one, in-
deed "the problem of problems" in our science.
The works on magmatic phenomena have been
concerned mostly with their development and
with the regularity in the distribution of igneous
formations in space and time. We have learned
many of the laws governing the distribution of
endogenetic rocks in various structures, folds,
faults, zones of crushing, in shields, platforms,
geosynclines, oceans, etc. Withal, the relation-
ship between crustal movements and magmatic
phenomena has been studied but little or in some
narrow aspect. The "fixist" approach to the
"tectonics-magma" problem, prevailing at
home, cannot get to the essence of it because it
cannot tackle the genetic relationships between
the two phenomena. Unfortunately, a vast
majority of petrographers, geochemists, and
geophysicists are bound by conventional views
on the leading and even exclusive role of vertical
crustal movements.

In the meantime, a look at the present status
of the world science of tectonics reveals that
there are but few defenders of "verticalism", as
staunch as ours. Even P. Van Bemmelen, whose

views are similar in many instance to those of
V. V. Belousov, is forced to concede the im-
portance of horizontal block movements, as
witness his latest article translated into
Russian [3].

Recently, more and more Soviet geologists
have adopted a broader approach to such move-
ments and attribute great importance to lateral
shifts as well.

The recognition of the block structure of the
crust and the importance of lateral movements
of the individual blocks is the main point of
modern theoretical tectonics. This article is
an attempt at a broad approach to the "tectonics-
magma" problem; it also develops some points
mentioned in my paper read before the Inter-
national Geological Congress [23].

1. STRUCTURE

The most important modern premise of tec-
tonics, the one that forces a revision of many
concepts, is that the crust and perhaps the upper
mantle are broken up into blocks, not only by a
system of steep to vertical fault surfaces but by
flat to horizontal surfaces.

In studying new geologic maps, particularly
those of strongly deformed provinces; i.e., in
considering the structure of the upper crust in
a horizontal section, we note innumerable frac-
tures as well as minor and major faults, in
places with evidence of considerable displace-
ment of some blocks. In folded provinces,
where rocks are deformed very strongly, num-
ous fractures are exposed in all outcrops. An
experienced geologist evaluates the deformatic
of a region not only from the dip of the beds but
from the nature and degree of crushing and fro
the results of physical and chemical changes i
rocks, following the obvious and purely mecha
cal shifts in the segments of a bed, massif, a
series of beds, or the crust as a whole.

[1] Tektonika i magmatizm.

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However, the block structure of the crust can not be seen in a horizontal section alone. The same multitude of tectonic surfaces can be seen in a vertical section. What is more important, we see here the flat or nearly horizontal fractures and faults, in addition to the steep and vertical ones. Many geologists virtually dismiss them without attributing to them any significance in the structure and geologic life of the crust. It is tacitly implied that crustal blocks either wedge out downward or are not separated from their deeper roots and thus can shift only vertically. As a matter of fact, tectonic blocks are separated by both vertical and horizontal fault surfaces. These latter tangential surfaces are essentially the same as the steep radial fault surfaces. Present among them are small shears with an insignificant displacement, as well as major slip surfaces and the giant surfaces of differential shifting, as enduring as the deep radial faults. Deep tangential fault zones, located as they are in regions of high pressure and temperature, are the zones of "plastic flow", ultrametamorphism, and primary magmatic centers.

The presence of these tangential faults deep in the crust and the upper mantle can be inferred from similar zones in the upper crust. Thrust surfaces in many folded structures undoubtedly are segments of formerly continuous and deep-seated tangential slip surfaces.

In recent years, new facts of the deep structure of the earth have been ascertained from deep seismic sounding, here and abroad [5, 8, 9, 10, 11, 26]. In my opinion, they testify to the main feature of the upper reaches of the earth — its tectonic differentiation into heterogeneous blocks, lenses, slabs, and envelopes. Thus, a deep seismic profile 200 km long in northern Karelia has revealed, from the elastic properties of the crust, a thinner stratification of the crust than that implied in the notion of the upper (Conrad) and particularly the lower (Mohorovicic) boundaries of the basal layer. In Karelia, as well as in other regions, two discontinuities are better developed. One of them, 34 to 38 km deep, has been assigned to the surface of a subcrustal layer; the other, at 10 to 15 km, to the surface of the basalt layer. In addition, there are three less distinct discontinuities, at 5 to 7, 16 to 20, and 24 to 26 km. Characteristically, all these surfaces, although not quite horizontal and not quite parallel to each other, are consistently flat along the entire profile. This stratification of the crust into comparatively thin slabs, in the Baltic shield region, is similar to that observed earlier by Yu. N. Godin, in the eastern part of the Russian Platform.

It is of interest that present along with this "macrostratification" of the crust in Karelia are more or less steep zones of considerable wave damping, as if breaking up the continuity of the flat to horizontal contacts of the deep layers. These steep zones of changes in seismic waves are believed to be deep fault zones visible at the surface and often accompanied by igneous bodies. The abrupt changes in physical properties of rocks, which affect the velocity of seismic waves is explained in different ways by different authors. Where vertical contacts have been inferred from parametric seismic soundings, the rapid horizontal changes in velocity, as well as the segments of abnormally low velocities, are taken to be zones of deep faults. In other instances, as in explaining the Mohorovicic and Conrad discontinuities, the authors and many other scientists associate the velocity change with a change in the composition of deep-seated layers. There remain some obscure points. For example, the 5 to 7 km deep flat discontinuity cuts steep folded structures; accordingly, the authors believe that it is best interpreted as a density change because of higher pressure and temperature.

It appears to be more correct, however, to interpret that and other similar discontinuities "cutting" the folded gneisses as fault surfaces. In support of this assertion I cite my observations in Sweden and Norway, in the summer of 1960, on overthrusts excellently described by B. Asklund and other Scandinavian geologists [27, 28].

The Caledonian thrusts in Sweden and Norway are remarkable in that they involve mostly gneisses of the platform basement, overlain by thin, strictly platform-type lower Paleozoic deposits. The tectonically differentiated flat slabs of Archean gneisses, resembling from a distance slightly disturbed sedimentary series, rest upon the lower Paleozoic of the platform. Scales, faulted off from the marginal part of the shield, have been pushed far over it or, more precisely, the shield has been pushed under them. The tectonic stratification of the Archean proceeded unquestionably at a considerable depth and was brought to the surface only as a result of Caledonian folding; consequently, it displays the inner deep structure of the gneisses. It may be assumed that this horizontal tectonic stratification, sliding, and "mass flow" are present in those deep sial intervals of the Baltic shield where there are no thrusts. Probably these surfaces have been detected by deep seismic sounding in Karelia and elsewhere.

The tectonic differentiation of the crust, accompanied by magmatic phenomena, is probably much more complex than we infer now from the few seismic data. First of all, a correlation of such discontinuities over large areas is as yet unreliable. It is quite possible that the Mohorovicic discontinuity, occurring at various depths, and the Conrad and all other similar discontinuities, have a tectonic and structural significance. Each of them is not an unbroken surface but rather a thick tectonic zone where

individual shearing, sliding, and flow surfaces may overlap en echelon. Generally speaking, the crust cross-sections are apparently more complex and diversified than we assume. Undoubtedly, the various deep crustal sections, now merely guessed at, will be known with the development of geophysical works and deep drilling; as a result, we shall see a great heterogeneity in the deep reaches of the earth, "facies" changes, so to speak.

Such being the case, it is only natural that each major, structurally independant block will differ from its neighbors, particularly so from the overlying and underlying blocks, in size, composition, thickness, density, and position in the over-all "stream" of that movement of crustal and subcrustal masses which constitutes the hydrodynamic essence of tectonics. This movement, expressed at the surface as folding, thrusts, and nappes in compression zones, and as grabens and genetically related troughs in tension zones is traceable down to great depths (as much as 700 km), judging from the foci of deep earthquakes. Sutures and boundaries between the blocks are subject to uneven stresses, in a differential movement; this probably is the reason for many specific features of igneous activity and tectonics.

However, before considering those features, we must pause for another and perhaps the most important feature of the crustal structure, also revealed by geophysics. This feature has not been fully accounted for by tectonists and petrologists in their theoretical considerations. I mean here the lack of homogeneity and the distinct tendency for abrupt lateral changes in the crust, on a large scale involving the continents and oceans, folded provinces and platforms, geosynclines and geanticlines. In short, we deal here with the fundamental tectonic elements, the structure of the crust as a whole and its major blocks.

Gravimetric and especially seismic data on the structure of the crust reveal the presence of two crustal types, continental and oceanic. Their specific features are well known, and are best outlined in the V. V. Fedynskiy paper [26] read before the Twenty-First Session of the International Geological Congress.

The oceanic type section is characterized by either a complete absence or by a very thin interval of both the 5.5 km/sec sedimentary layer and the 5.5 to 6.5 km/sec granite layers. The basalt layer, with a longitudinal wave velocity of 6.5 to 7.0 km/sec, is locally not thicker than 5 km. Underlying the Mohorovicic discontinuity is a subcrustal layer with a velocity of longitudinal waves of about 8 km/sec. A section of the continental crust is characterized by much thicker sedimentary, granite, and basalt layers. In platforms, the crust is generally 30 to 40 km thick, attaining 70 km in some mountain

provinces of Asia. Besides these two principal types there are of course intermediate types of a thicker (40 to 45 km) or thinner (15 to 20 km) crust.

We are especially interested in the fact that certain areas of abnormal crustal thickness happen to be comparatively small, commensurable with individual geosynclinal troughs, major grabens, and geanticlinal uplifts. For instance, the South Caspian, Black, Red, and Mediterranean Seas basins are areas of a decidedly thinner crust; the opposite is true for the Main Caucasian Range, the Alps, and the Appenines. On the whole, the Mediterranean-Alpine zone is marked by large gradients in crustal thickness, which explains many specific tectonic features.

Some students [1] have voiced serious doubts in the logic of inferring the composition of layers of the crust and mantle from the velocity of elastic longitudinal waves. Generally speaking, physical properties determining the various velocities depend on thermodynamic conditions; consequently a final solution of the problem of the subcrustal stratum and of the lower crust will be obtained only from super-deep drilling. We believe, however, that the totality of geologic and geophysical data is adequate for correlating the change in physical properties with composition, first of all. This is hardly to be disputed with regard to the granite continental layer and the basalt oceanic layer.

The existence of clean-cut discontinuities, too, suggests a sharp difference in the composition of the several crustal zones; it cannot be explained by changes in temperature and pressure, which are gradual from place to place rather than abrupt.

The mosaic pattern of physical fields (gravitational, magnetic) corresponding to those of geologic structures suggests that different crustal varieties are indeed characterized by a difference in composition; and that the basalt and granite layers indeed exist as such in those places where we observe the corresponding geophysical constants. We cannot overlook the long known fact that acid rocks are absent almost everywhere throughout the immense Pacific, beyond the andesite line. Nor can we overlook the fact, recently stressed by Yu. A. Kuznetsov [16], that huge bodies of granite batholiths occur mostly in areas of a thicker granite crust.

Finally, a third and brand new group of facts to be considered in speaking of the general aspect of the crust and the subcrustal stratum, has been obtained through the rapidly developing study of sea and oceanic bottoms. The most pertinent data are cited in the works of G. B. Udintsev [25], A. V. Zhivago [12], V. P. Goncharov and Yu. P. Neprochnov [9], H. Minard, and others. With space enough for a mere summation, it can be stated that perhaps both the

continents and the ocean bottom are affected by the same tectonic fragmentation into blocks of various sizes, subject to considerable relative displacements. The giant bottom faults with volcanoes occasionally "nestling" in them are even better expressed, morphologically, than in the continents, in immense crevices, escarpments many hundreds of meters high, steep ridges, and troughs. Thus it appears that both crustal tectonics, fully developed in the continents, and upper mantle tectonics structurally expressed in the oceanic bottom, have much similarity in their essential features. Obviously both are subject to the same laws of fragmentation and movement, with a development of faults planetary in dimensions. These are facts of tremendous theoretical importance.

Thus, the entire globe with its continents and oceans is characterized by a block-mosaic structure involving both the crust and the upper mantle. These deformations are the result of a tremendous expenditure of energy.

It should be emphasized that the crustal structure is not a chaotic piling-up of blocks; on the contrary, it is extraordinarily orderly. The major and minor tectonic sutures, and the folds and folded zones, form a strictly regular pattern of forms and combinations of forms, in both plan and profile, all subject to general laws of block movement during long periods of geologic time. A consideration of these special structural problems, although more familiar to me, would take me far away from the subject of magmatic phenomena. Accordingly, this article deals only with the main characteristics of crustal block movement, just enough for petrogenetic considerations. Our conclusions are based on a study of the crustal structure and its development, primarily in Eurasia.

2. THE MOVEMENTS

Crustal blocks are shifted in three-dimensional space; consequently a differentiation of their movements into "horizontal" and "vertical" is often purely conditional. We can speak of vertical and horizontal components of shifts of a block, segment, or zone of the crust.

On the basis of long personal experience, I believe that both the vertical and horizontal components of these shifts are the effect of a single cause, namely tangential rather than radial tectonic stresses. One cannot agree with the popular concepts placing paramount importance on vertical forces and stresses and giving horizontal ones a subordinate role. The reverse has been observed. All structures known from the crust and the upper mantle, as well as their evolution, are best explained by tangential forces, so that there is no need to drag in some hypothetical primeval vertical

forces to account for geologic structures. Such forces are purely hypothetical. We believe, from our analysis of structures and movements, that tectonic shifts involving huge crustal masses are a result of the gravitational-inertial forces of this planet, expressed, among other ways, in the occasional abrupt changes in the angular velocity of the earth's rotation.

If that dynamic factor, external in relation to the earth, is accepted as the prime force which brings about geologic phenomena, as well as perhaps similar processes on other planets, the mechanism of the tectonic shifts observed is quite readily explained. It is probable that as a result of gravitational-inertial forces, the earth's crust, heterogeneous and extremely unstable, mechanically, and consisting of blocks of different density, will tend to acquire a new mechanical equilibrium. In that operation, each structurally isolated block, more or less homogeneous in itself, will naturally posses a displacement "potential" of its own. It is this certain independence in the shifting of at least major structurally-isolated blocks that constitutes the essence of tectonic movements. No tectonic theory has as yet recognized such a mechanism in the movement of the crust; none has realized that each block had what may be called "motive power" inherent in it. The mechanism of tangential crushing of the crust, in contraction, as well as vertical crushing, cannot explain the many peculiar features of crustal structure and the tectonic shifting of blocks, just as these phenomena cannot be explained by differential vertical movements.

The paramount feature of tectonic movements is the differential nature of the block movement. A study of the vertical component has long since led geologists to the unanimous conclusion of its differential character, but no one has pointed out that the same is true for the horizontal component. What is more, it is the differential nature of tangential movements that renders this quality to the vertical component.

This differential nature of horizontal block movements; i.e., their different speed and consequently the magnitude of displacement for the same time interval is a result of the blocks' heterogeneity and the lack of uniformity in the mass movement within the crust and the upper mantle. The velocity gradient, always present in differential movements along the margin of the blocks, determines the nature of the regional geodynamic field. Predominately compressive stresses originate along the front of a faster block, at the contact with slower blocks in front of it. At the same time, tensile stresses originate back of a faster moving block system. The local geodynamic field (the presence of compression or tension in a crustal segment) is of course quite changeable and dependent on many factors; still, the familiar and persistent

inherited development of many major geologic structures, in the same direction, is a result of the great stability of a regional field, in time. This stability of compressive and tensile stresses in given zones is related to the irreversibility of tangential shifts.

It is hardly necessary to demonstrate that compression and tension are inseparable in geologic phenomena and structures; they are always coexistent and interrelated. In space, however, there always is a certain division of stresses because of a geological "selection" of either compression or tension in certain places and zones, in accordance with the general geodynamic field of the earth and with the differential nature of the shift among major blocks. On the other hand, a division of compression and tension in time, and an alternation of the compression and tension epochs involving the entire planet, finds no corroboration in geologic structures. The authors of the pulsation hypotheses associate the periodicity of tectonic movements with some as yet unknown internal causes of compression and tension. As a matter of fact, what we are observing is a periodic acceleration and slowing down of tangential block movement, leading to local compressions and tensions. In a given segment of the crust, compression indeed may be followed by tension, but it does not mean that the entire globe is so affected, at the same time. On the contrary, a compression in some segment is unavoidably accompanied by tension in some other.

This theory of an independent shift in homogeneous, structurally isolated crustal blocks, independent because each of them has a mechanical movement of its own, in a changing gravitational field of the earth explains the main features of tectonic movements, namely their differential nature, periodicity, and the simultaneous existence of tension and compression zones. Compression structures along the front of a given system of blocks cannot be explained by a push to these blocks from behind, because it is just there that tension structures often develop, at the same time. Geologists have long since been familiar with the asymmetry of tectonic zones and major structures, as emphasized in the familiar synthesis by E. Suess who widely used the terms, "foreland" and "backland". It is hardly necessary to explain that this structural feature is of course related to a zonal distribution of stresses along the block margins with different shift velocities.

The lack of lateral homogeneity among the blocks, as determined geologically and confirmed geophysically, is of prime importance in determining the regularities in the origin, development, and distribution of deformation in the crust. That interesting subject is beyond the scope of this article. I will mention only the general features of the more familiar Mediterranean-Alpine zone.

The extreme heterogeneity of that crustal segment has been determined geophysically. The most remarkable fact is the presence here of areas with a very thin, if any, granite crust, in deeper parts of the Mediterranean, Black, Caspian, and Red Seas basins. Some students are inclined to think that this differentiation of the crust occurred in the most recent geologic times, being related to the alleged oceanization phenomena of the Mesozoic [2] or with a flow of sialic material away from the ocean basins [21]. However, a more rational approach to the geologic phenomena observed, with some consideration given to the inheritance principle and to the forward movement of major crustal blocks, the only ones with which we deal here, will lead to an assumption that the earlier Mesozoic and Paleozoic Thetis, too, was marked by similar "rents", "windows", and "holes" in the crust or in its granite layer. Moreover, considering the geologic development, it may be supposed that these "holes" had been more extensive, merging at an early stage into a vast province of oceanic crust, with only small "granite islands" standing out during the middle Paleozoic. It appears then that the development here most likely proceeded in a direction opposite to oceanization.

The specific geologic features (and above all, the igneous formations) in the Mediterranean-Alpine zone, as well as the tectonic features (and above all, the thrusts), are explained by the extremely great velocity gradients in the displacement of segments of thick and thin crust — gradients much larger than for the similar continental crust. These gradients and the "holes" in the granite crust offer no substantial resistance to a later shift of adjacent sial blocks, with friable sedimentary sequences literally crushed between them.

In the summer of 1960, in cooperation with N. A. Shtreys, I became acquainted in considerable detail with structure and sections of the Albanian dinarids. The excellently developed dinarid nappes (Toska and Mirdita), best characterized by extensive early Mesozoic ultrabasic to basic igneous and sedimentary rocks thrust over Eocene flysch, are the result of a deformation of one such "crustless" downwarp. There are no reasons at all for regarding these nappes as having been thrust over from far in the north. They originated right here, within the Toska-Mirdita zone, as a result of shearing and sliding of the sedimentary layer along a surface roughly corresponding to the Mohorovicic discontinuity.

I believe that many if not all eugeosynclines originated in a thin crust or directly on the subcrustal layer. Deep troughs of the Ionian, Black, and other seas are such modern geosynclines. Geosynclines similar to some Mesozoic and recent Mediterranean ones are residual after earlier and larger expanses of oceanic

crust; some others are newly formed as a result of extension of the granite layer. Such structures are like the Silurian greenstone troughs of the Urals, crushed in the late Paleozoic.

Deformations originating in troughs of a continental type crust, such as the deformations in the middle and late Paleozoic troughs of Kazakhstan, Tien-Shan, and South Siberia, are known to be quite different from the Alpine type. The main difference lies in the absence here of true nappes, although large overthrusts are present; and in the utterly different essentially "granitic" igneous activity. A gigantic compression of the crust, already sufficiently strong by the early and middle Paleozoic, had led to its regeneration and to the formation of huge granite bodies and of acid and intermediate extrusives.

As we have seen, the differential nature of tectonic movements is apparent both laterally and in depth. The velocity gradients are undoubtedly present also in tangential displacements of blocks and heterogeneous slabs divided by discontinuity surfaces, both within and under the crust. The highest gradients occur probably between the granite and basalt layers and between the latter and the underlying layer.

These differential movements bring about a very substantial feature in the deformation of any folded province; viz. , an alternation of zones, belts, and segments of quite distinct deformations. The junction zones of large blocks, which are the loci of high and long-enduring velocity gradients, are represented by major and long-developing assorted zones of folding. The interior of these zones does not present an orderly arrangement of similar deformations, i. e. , folds and faults. Locally, as at junctions of the blocks; i. e. , in zones of faulting and crushing, the intensity of deformation is much higher; in other places, contemporaneous beds rest comparatively undisturbed over broad areas. I do not believe there is any need to describe in more detail the lateral heterogeneity of deformations quite familiar to all geologists.

The second most important feature of horizontal block movement is its irreversibility. On a smaller scale, this regularity has been known for a long time, as expressed in the statement that the so-called "folding" movements, unlike the "oscillating", are irreversible. This, however, is but a specific example. The irreversibility of tangential movements of tectonic blocks is of great general importance and explains many other specific regularities.

Throughout Eurasia, this irreversibility, for at least the last billion years; i. e. , for the entire Neogeic megachron, transpires from the study of tangential shifts among blocks separated by deep faults, also having developed during the entire megachron. In this connection, the study of those faults which bound vast structural patterns typical of Eurasia becomes especially important — the pattern lending itself to an interpretation with respect to the movement of the blocks and to the origin of structures. If the origin of the most common structural complex is deciphered in one or two places, the same origin may be attributed by analogy to structures identical in pattern in other places. The assumption is that a structural pattern or an orderly complex of similar tectonic forms has the same origin, irrespective of place and time.

By using this method, a general picture of the crustal structure and movement over a large area can be arrived at. As an example, in the most typical structural pattern of the area from Lake Baykal to the Caspian Sea, we readily perceive that it is defined essentially by two systems of deep faults, whose development goes back at least as far as the Riphean. One system has a consistent northwestern trend and is marked by the amazingly straight lines of component faults, over hundreds of kilometers. The other system trends northeast; unlike the first, it is less consistent and exhibits complex bends, arcs, virgations, and crowdings of faults with a development of thrusts. Emerging as a result of the two, there is an orderly structural complex, well illustrated in western Tien-Shan. Here, this complex consists of three types of structures: 1) a deep Fergana-Talas fault with a well defined lateral component; 2) a system of virgating folds and steep thrusts of the Chatkal-Kuramin province, convex to the northwest, and abutting the deep lateral fault from the southwest; and 3) a system of large and small, long and narrow blocks of the Talas zone, extending along the deep fault, and made up of older rocks.

The formation of this complex of three structural types is related to a right-lateral movement along the Fergana-Talas fault. According to the most recent data of V. S. Burtman, its magnitude, during the late Paleozoic, was 200 km. These data refine and definitely corroborate the earlier studies by V. N. Ognev [22], V. B. Vongaz [6, 7], V. G. Korolev, and others.

It is readily seen that the huge Sayan-Altay Caledonian complex, with the large east Sayan fault the main northwestern right-lateral fault, is similar to the West Tien-Shan complex.

My own studies in Central Kazakhstan, and particularly the latest works by A. I. Suvorov [24], have shown that the major and long-active northwesterly faults of the Chinghis, Aktas, and Dzhalair-Nayman type, represent right-lateral faults. The structural pattern of Central Kazakhstan, defined by the northeasterly Spassk and Uspensk zones, in conjunction with the Chinghis structures, was formed on the whole as a result of differential right-lateral

displacements of blocks, similar to those in western Tien-Shan and in the Siberian caledonids.

If we add to this the similar pattern of the Pamir-Hissar structural complex formed probably in the same way but in Alpine time, our case is complete for the irreversibility of block movement to north and west, in that part of Asia, beginning in the early Paleozoic.

Essentially the same picture has long been established for the Alpine and Hercinian structures of Europe; a drift of the blocks to west and north and the prevalence of the same systems of deep faults in the structural pattern, as is the case in Asia [4]. Here, the major northwesterly sutures appear to have been developed mostly as right-lateral faults; joining them from the southwest, in an abutting, virgation, or "horsetail" pattern, are structures trending generally to the northeast and characterized by a different dynamic regimen and by a different geologic history. It is not to be inferred from this exposition that there are no other faults except for the diagonal in Eurasia. Such faults are known but they do not affect our conclusions.

It is of interest that structures developed along left-lateral rather than right-lateral faults are present in eastern Asia, east of the Irkutsk amphitheatre. At the same time, here, too, there is a general drift of blocks to the north and mostly to the west. Incidentally, as established in a number of works by Ye. A. Kuznetsov, left-lateral faults are developed in the Urals, while we have observed right-lateral ones in the Scandinavian caledonids.

It appears then from structural features that the movement of blocks fringing the Russian and Siberian Platforms in the southwest, south, southeast, and east proceeded at a higher rate than the movement of the platforms themselves, although the direction of movement was the same in both places. Because of that, a velocity gradient had persisted for a long time, along the southwestern, south, and southeastern edges of these northern platforms, even since their inception as structurally separate blocks with a well defined displacement "potential" of their own, in an irreversible westerly drift. This phenomenon explains the presence here of inherited structures as well as their specific features.

I pass over the many most interesting examples and details, to pause for one province whose geologic structure and development has not been explained as yet by any tectonic theories. This is the southeast fringe of the Siberian Platform with the following distinctive features: 1) a very thick granite crust, to judge from geophysical data; 2) a development of granite-metamorphic rocks unique in scale and importance; 3) the consistent appearance of granites, including those of Mesozoic age, when there was not even a trace of geosynclinal folding; and 4) intensive tectonic activity persisting to the present.

These and other specific features of that province are explained by the consistent predominance of compression (with only local tensions) at the junction of the less mobile province of the Siberian Platform and the more mobile blocks to the southeast. The critical factor here was the northeasterly trend of the platform edge, which hampered the comparatively unobstructed northerly and westerly drift of the blocks. As a result, there was a huge piling up of sial blocks going on for a long time and bringing about a considerable thickening of the crust.

The irreversibility of tangential movements of crustal blocks explains one of the most important features of geologic development, namely the inheritance principle. Naturally, had these movements been reversible and haphazard; i. e., if the blocks had moved west at some stages and south or east at others, there would not have been the order that we see now, let alone any inherited and consistently developed tectonic structures. What is more, there have been many uplifts and downwarps developing in the same direction for almost a billion years. This is because the irreversibility of differential lateral shifts of the blocks and heterogeneous layers of the crust and the mantle is preserved even in an abruptly changing gravitational field of the earth, and despite the phase aspect of geologic phenomena. It is difficult to explain a persistent and confined structural heritage, by some localized processes, preferably deep-seated. On the other hand, as seen from our point of view, the irreversibility of tangential movements and a long and consistent inherited development of principal sutures and structures is as obvious as the inexhorable rotation of the earth from west to east.

Tectonic forces and the vector of irreversible tangential tectonic movements may be regarded as inherent, immanent but ever mutable properties of this and probably other planets, being related to more general laws of motion for cosmic bodies rather than to the evolution of matter within each planet. By the same token, the obvious "endogenetic" phenomena, igneous activity and heat currents, may have for their ultimate cause gigantic external mechanical energy with relation to the earth; in other words, such pehnomena are secondary. Here we bring up the subject of a revision of concepts popular among the geologists, on the relationship and nature of geologic phenomena. Geologists should present astronomers and astrophysicists with the possibility of an appreciable change in the gravitational field of the solar system, even for the relatively short interval of about one billion years of the Neogei-

megachrone, because of the obvious evolution of geologic processes originating in that change.

The irreversibility of the horizontal component of the movement explains the consistency of the plan and the consequent development of main tectonic zones and deep faults, as well as the asymmetry phenomena in principal structures, utterly inexplicable up to now. The Russian platform is asymmetric, with the Baltic shield representing an ancient piling up of sialic material along its northwestern frontal margin; so are the Urals and the Appalachians with their sharply differing western frontal and eastern rear parts; quite asymmetric are tectonic structures of Siberia, especially those east of the Siberian Platform; and so are the Caucasus and the Mediterranean region. In short, all major tectonic systems are asymmetric.

This asymmetry, quite conspicuous on a large scale as a result of the entire known geologic history, can be understood only in the light of the irreversible tangential crustal movements. Each structurally isolated homogeneous tectonic unit or zone has its front and rear, which is natural in view of the differential movement of such units, with compression structures prevailing at the front and tension structures in the rear. Thus, characteristic of the front of the Russian platform, from the Caradocian to Devonian, was a giant Caledonian compression resulting in the folding of Scandinavian caledonids and in a deformation of the northwestern margin of the platform; in the rear, in the meantime, there was a general and appreciable extension of the crust and the formation of crustless troughs. Significantly, the mass flows of a basic magma in Silurian troughs of the Urals coincided with folding phases in the Scandinavian caledonids.

The front of the upper Paleozoic Urals was represented by a compressive Uralian foredeep, while the rear was represented by the Trans-Urals with its late Paleozoic and early Mesozoic volcanic troughs. In the upper Paleozoic of Central Kazakhstan, such major northeastern to sublatitudinal faults as the Spassk and Uspenskiy were zones of high velocity gradients for tangential movements. Developed in these zones were schistosity, thrusts, metamorphism, autochthonous granites, and other phenomena associated with compression. Developed at the same time farther north were large amagmatic downwarps (Karagandinsk, Teniz, etc.) which may be regarded as the result of crustal warping and compression, as against the contemporaneous volcanic rear trough of the Balkhash region where a greater permeability of the crust is probably due to tension.

I pass over the familiar Alpine structures of Europe where front and rear structures have long since been known. However, my very first attempt to compile paleodynamic maps of Eurasia, from magmatic phenomena, suggests a very inconsistent, laterally, geodynamic field; that, as has already been noted, can be true only if the tectonic blocks have a certain independence in their differential tangential movement.

At this point, it is natural for the reader to inquire as to the magnitude and velocity of these tangential movements. Unfortunately, we can speak only of the magnitude of relative movements of individual blocks of the continental crust; we can say nothing of the velocity and magnitude of movement for the granite crust as a whole, because not a single block is stationary and there is no reference point.

The problem is even more complicated by the fact that, theoretically, there should be a difference in the velocity of eternally unidirectional tectonic movements for mantle material and the basalt, granite, and sedimentary layers.

In the meantime, the known values of relative block movements, within the continents, are rather low. Their cumulative value, because of the irreversible nature of their horizontal component, is appreciable only after a long geologic time interval, and it increases with the difference in adjacent blocks. It is best appreciated from the magnitude of the largest lateral fault movements and thrusts. Thus, the Middle Carboniferous - Triassic movement along the Fergana-Talas lateral fault is 200 km; the Jurassic-Pleistocene movement along the New Zealand Alpine fault is about 500 km; the Jurassic-Pleistocene along the San Andreas fault is 500 km; and the Caledonian stage of the Great Glen fault is 100 km.

The magnitude of the lateral rapprochement for individual blocks in the Alpine Mediterranean zone, from the Triassic to the Pleistocene, is not over several hundred kilometers, judging from structural and paleogeographic data.

Taking into account the irreversibility of movement, the relative shift in adjacent blocks along deep faults active for several epochs of folding, is not likely to exceed 1000 km.

For these reasons, I cannot agree with the extreme mobilists of A. Wegener's camp. It should be noted, however, that if blocks with such comparatively small displacements can exist in the granite layer, a much higher velocity gradient should prevail on the Conrad, Mohorovicic, and other boundaries of major heterogeneities.

It should be stressed that lateral faulting has engaged the attention of many geologists, in recent years. A well substantiated analysis of

this subject is given in a number of foreign works [20]. This interest for lateral faults is understandable, because they present a "touch-stone" for tectonic theories. The believers in contractionism, of all persuasions, try to play down the importance of large lateral move-ments; the extreme fixists, who recognize only the vertical "oscillatory" movements, often altogether deny the existence of lateral move-ments and in effect reduce the nappes to a vari-ety of land creep. The advocates of the theory of subcrustal convection currents, too, cannot explain the lateral movements, as admitted by A. Eardley [13], himself an adherent of that view. We believe that the lateral movements are given their proper place in our own theory.

We have considered the main features of tangential movements and stresses which ap-pear to be related, as seen from the generalized geological data, to outside factors, namely to gravitational forces of the earth. We have only touched upon the role of the vertical component whose properties essentially follow from those of the horizontal component. The most probable common cause of the vertical component; i. e., uplift and subsidence, is warping and bending of the crust under compressive stresses, and sur-face subsidence as the result of extension of the crust. The total vertical displacement cannot exceed the thickness of the crust, which indeed is the case.

Geophysical data suggest that many uplifts are associated with a thickening of the crust; we believe this due to a twisting of the blocks, their tangential piling-up and merger during a long geologic interval in zones of stable velocity gradients for tangential movement.

Secondary tectonic forces derived from the energy of magma also may cause uplift and subsidence; such deformations are, however, of small importance.

The only obscure point remaining is the role of vertical subsidences caused by the earth's contraction, if such a phenomenon exists at all.

3. MAGMATIC PHENOMENA

With reference to the broad subject, "mag-matic tectonics", we will touch in a most gen-eral way only upon those aspects of it which we believe to be directly related to features of structural heterogeneity of the earth and to zonation in the crustal geodynamic field.

Formerly, when many petrographers be-lieved, as F. Yu. Loewinson-Lessing did at the outset of his work, that the interior of the earth was a primeval magma existing since the be-ginning of time, there was no question of its origin. The petrographer's task was reduced essentially to a study of the composition of endogenetic rocks, their distribution in space and time, with reference to geologic structures, and to a theoretical substantiation of the obvious fact that there were more rock varieties than could be accounted for on the assumption of a single or even of two primary magmas. The phenomenon of magmatic differentiation, always present in one form or another, was discovered and geologically substantiated in that connection. However, the problem of inconsistency and the great diversity of rocks was not solved. New phenomena were discovered in the course of study. As of now, all petrographers seem to be in accord that, besides active magmatic melts originating either in a direct fusion of solid rocks or in their selective mobilization, there undoubtedly exists a chemical transfer of matter by diffusion, with the formation of a long series of metasomatic rocks. That discovery has con-siderably broadened our ideas on endogenetic rocks in general.

However, as long as the existence of magma is universally recognized, the problem of its origin remains; any solution of it affects to a certain extent our views on the essence of geo-logic phenomena.

At present, magma is practically never con-sidered apart from tectonics; so that if the origin of tectonic movements is established, the origin of magma will also be established. It is impossible that magmatic phenomena and tectonic movements are brought about by dif-ferent factors and that only later do they enter a common path. In my opinion, such an as-sumption became invalid when it had become clear that magma was not a primary substance but a melt which originates anew, in some places, at certain times, and with a considerable energy expenditure. The main sources of that energy are mechanical movements of matter in the crust and the mantle, either in plastic flow or in displacement of large and small blocks along fractures and faults, and caused by ex-ternal gravitational-inertial forces.

In a number of his works, P. N. Kropotkin [14, 15] demonstrated mathematically the great importance of heat generated in mechanical tec-tonic movements. However, even direct geo-logic observations show that it is the points or zones of "application" of tectonic forces, or more precisely the zones of high velocity gradi-ents for block movements, and consequently of high pressure gradients, that control the forma-tion and to a considerable extent the distribution of igneous rocks.

The various tectonic sutures, such as deep, radial faults and deep tangential shear zones at places where magma is generated. Anticlinoria the axial zones of folded structures, as well as all zones of piling up of sial blocks, are known to represent granite belts and zones of meta-morphism. It is hardly necessary to cite any

specific examples. Such belts are usually marked by autochthonous and parautochthonous granite massifs, while allochthonous bodies which do not form large unbroken belts usually occur in zones of tension.

An analysis of tectonic movements has shown that a regional geodynamic field is zoned, with the simultaneous presence of belts of predominant compression and predominant tension. This leads not only to a separation of zones with different permeability to magma but also to a change in thermodynamic conditions where the compression zones with their particularly intensive displacement of matter may generate melts as the result of a temperature rise, while in the zones of tension the same phenomenon may accompany a pressure drop.

A spatial differentiation of stresses and the lack of uniformity in the geodynamic field are the causes for the lack of uniformity in the heat flow throughout the earth. The maximum amount of heat is known to be generated in zones of intensive tectonic movements.

Deep shear zones bounding the heterogeneous blocks probably are the most important tectonic structures in the forming of magmatic melts. In some instances, such as the very uniform platform basalt flows spreading simultaneously over large areas, and often having an areal rather than linear zonal distribution, the forming of a basalt melt is quite difficult to associate with anything other than the deep and areally extensive tangential zones of shearing and displacement in the basalt or a deeper ultrabasic layer. The mechanical energy liberated at such a shear surface may be sufficient to raise the temperature and to fuse immense expanses of eutectic basalt melts. If, as we assume, the velocity of horizontal displacement is different for the crust and the deeper layers, it becomes understandable how such shear surfaces and a layer of basalt magma may originate at depths from tens to a few hundred kilometers, and simultaneously over a large area.

In considering magmatic phenomena in the light of the physical composition of rocks, we must go back to F. Yu. Loewinson-Lessing's idea which he defended to the end of his life, namely the concept of two magmas; basalt and granite. By now, probably everybody agrees that all magma is a product of fusion. Such being the case, the two main anatectite types, granitoids and basaltoids, have undoubtedly existed as early as the Archean. They are related to the two main layers of the earth, granite and basalt, persisting since the most ancient times. Naturally, all anatectites formed in the granite layers have a granitoid composition; correspondingly, anatectites from the basalt layer are basaltic. In addition, it may be assumed that basalt magma originates in an ultrabasic layer. This general rule of the two

principal associations of endogenetic rocks was correctly perceived by F. Yu. Loewinson-Lessing. It is quite important in considering a number of structural magmatic and metallogenic problems. For example, the earlier classification of large deep-seated structures acquires a new meaning in the light of theories developed in this article.

First, segments, zones, belts, and provinces should be differentiated by their dynamics. That factor can be used in identifying the zones developing in a prolonged compression of the crust and therefore characterized by a limited permeability to volcanic products; also zones developing under conditions of prolonged tension resulting in a high permeability of extrusive formations. The structural differences of these zones have been mentioned before.

Zones almost completely free of volcanic formations are present in both the frontal belt of folded provinces and within geosynclinal provinces. It follows that the absence of volcanic rocks in these belts, termed miogeosynclinal by H. Stille, is related to the nature of the stresses rather than to a reduced mobility of the crust.

Second, in classifying geosynclines by physical composition of their principal rocks, they can be differentiated into two major groups: "granitoid" or secondary and "basaltic" or primary (eugeosynclines). The first type is developed in fault zones of the continental crust; the second in fault zones of the oceanic crust.

To be sure, many intermediate types of geosynclines can be designated by physical composition of their sediments, because the crust is quite heterogeneous in petrography and structure. However, we are interested here in fundamentals rather than in details. Nevertheless, the great importance of differentiation should be emphasized, inasmuch as it may lead to the appearance of large volumes of intermediate and acid rocks in crustless "basaltic" geosynclines.

"Granitoid" geosynclines developed on a continental crust are the middle and late Paleozoic geosynclinal troughs of Tien-Shan, Central Kazakhstan, the Altay-Sayan province, and many others. "Basaltic" geosynclines developed in troughs of the oceanic crust include the Silurian-Devonian greenstone Uralian geosyncline, the Mesozoic ophiolite Mediterranean geosynclines, and certain lower Paleozoic and Riphean geosynclines of Kazakhstan and south Siberia. They are characterized by the absence of large "autochthonous" granitoid massifs, despite the extremely strong compression and deformation. Instead of the granitoids, there are huge bodies of basic and ultrabasic intrusions, which is quite natural because granitoids can occur here mostly as the result of a differentiation of basalt magma. The absence or only a slight

development of granites in many Alpine geosynclines of the Mediterranean region is sometimes explained by minor erosion. As a matter of fact, the erosion and the relief here are sufficiently large to expose any large granite bodies if they were there at all. On the other hand, in some crustless geosynclines, such as that represented by the Albanian dinarids, ultrabasic and basic rocks occupy almost a quarter of the entire area, so that there is practically no room left for the alleged deep-seated granites.

F. Yu. Loewinson-Lessing's concept of two magmas simplifies the problem of the diversity of endogenetic rocks. It should be added that the crust-mantle section contains many tectonic surfaces occurring at different depths and generating magmas according to the rock composition about those surfaces. It is probable that this, rather than differentiation, is the explanation for the great lateral diversity of contemporaneous outflows.

Commonly, the abrupt change in consecutive flows cannot be explained by the evolution of a single long-enduring magmatic hearth. Obviously, the complex zones of movement and stress gradients have a definite thickness for a given depth, so that a melt of a definite composition may be produced at a certain depth at one tectonic stage; and the melt of a different composition at a different depth and at another stage. This of course is not to deny the role of differentiation; it must not be assumed that all basic rocks are the result of a crystallization of basalt magmas, only, and cannot be differentiates of other magmas. Petrographers are familiar with granitoid rocks differentiated out of basic and ultrabasic magmas. Without these phenomena, seemingly universally accepted, the origin of a granite crust would be impossible to explain. To be sure, granitization phenomena with a transfer of matter from depths to the surface still have to be considered. And it is not quite clear whether granitization takes place at all in the absence of a magmatic melt in a given crustal zone, at depth.

These concepts of ours are new only to the extent that they assume anatexis and consequently a differentation of huge masses of the crust and mantle, of different composition, inasmuch as mechanical displacements and deformations involve, as we have seen, the deeper reaches of the continents and oceanic provinces. It is probable that the chemical transfer of matter from deeper to shallower levels, too, is connected with the presence of multiple magmatic centers at various depths. A sizable chemical transfer of matter in the crust and upper mantle is hardly conceivable without anatexis.

F. Yu. Loewinson-Lessing, to whose memory this article is dedicated, believed in anatexis but thought that the heat generated in deformation is inadequate; and therefore, views such as the well-known theories of the French scientists E. Haug, M. Lugeunes, and others, are inconsistent.

These, then, are the conclusions arrived at from a study of the principal structural features of the earth and its principal movements.

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F.YU. LOEWINSON-LESSING'S PART
IN DEVELOPING THE THEORY OF ORE DEPOSITS[1]

by

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F. Yu. Loewinson-Lessing was one of those outstanding scientists of the recent past whom we may call encyclopedists. Although he is rightly regarded as the father of Russian petrography and one of the greatest theoreticians, we must also render to him his due in other fields: pedology, crystallography, theory of ores, general geology, and geochemistry. His remarkable teaching career is not to be overlooked; he trained a number of scientists who now successfully develop the creative ideas of their teacher in various fields. F. Yu. Loewinson-Lessing always paid particular attention to the scientific initiative of his pupils, encouraging them to pursue their favorite trends. This is why the ranks of his students include, along with petrographers, experts in ore deposits, construction stone, physicochemical methods of study, mineralogy, experimental petrography, etc.

I am taking the liberty of singling out his influence and that of his school in the development of the theory of ore deposits.

F. Yu. Loewinson-Lessing started to teach a course on ore deposits in the Division of Metallurgy of Petersburg Polytechnical Institute, shortly after it opened in 1903. That course was quite abbreviated and consisted of two parts, general and special.

Having matured as a geologist and petrographer at the end of the nineteenth century, he developed, mostly the ideas of European scientists, in the field of ore deposits. In that he was prompted by his personal acquaintance with many of them and by his frequent visits abroad. The ideas of such authors of textbooks as A. Steltzner-Berge, A. Groddeck, F. Pochepnoi, Beischalg, Vogt and Krusch, and DeLonet were reflected in his lectures. His own original material obtained in the study of Uralian deposits of the Vysokaya and Blagodat Mountains, platinum deposits of the Syserta district, etc., was included in addition.

The general part of the course contained information on the nature and structure of ores, a classification of ore deposits, the mineralization processes, the origin of mineralizing solutions, secondary alteration of ore bodies, etc. Being familiar with contemporary chemistry, the author of a chemical classification of igneous rocks, and the editor of Browns' chemical mineralogy, F. Yu. Loewinson-Lessing emphasized the importance of chemical processes in the formation of ore deposits in the general part of his course. The second part dealt with deposits of individual metals (as in the DeLonet course). He modified that part, from year to year, alternating the emphasis on iron, manganese, and chromium, then on nonferrous metals.

It goes without saying that the teacher, being a petrographer, introduced much original material in interpreting the deposits of igneous-origin (magmatic, strictly speaking). He emphasized that the igneous rocks in which such deposits do occur are mostly basic intrusions, such as gabbro, norite, pyroxenite, labradorite, and peridotite. He assigned most such deposits to the syngenetic class, using a fairly broad meaning of that term. At the same time he noted, referring to Berge, that concentrations of ore are often the result of a "self-mineralization" rather than of direct precipitation out of the molten state. By that he meant the reaction between a hot, not quite solidified igneous rock and vapors (gaseous emanations) accompanying its crystallization. Autometamorphism phenomena were also touched upon in his earlier work, "The Olonetsk Diabase Formation", published in 1888.

While studying basic and related igneous rocks on the east slope of the Urals, F. Yu. Loewinson-Lessing turned to problems of the origin of titanomagnetite deposits in gabbro and pyroxenite, and of magnetite deposits in the syenite formation of Blagodat and Vysokaya Mountains. On the basis of those studies and of a careful correlation with published data on classic deposits, Kiruna and others, he evolved his own concept on the origin of a large group of deposits which he assigned to the magmatic

class proper. He believed that such ores were formed from ore melts obtained in liquation of mother silicate magmas to immiscible silicate and ore liquids.

The differentiated ore melt is then intruded, while fluid, into rocks where the deposits are now found. Epigenetic magmatic ore bodies, to which class he assigned the Mt. Blagodat ores, the magnetite deposits of Swedish Lapland (Kiruna etc.), and deposits of massive titano-magnetite ores, had been formed in that way. In addition, he identified syngenetic magmatic ore deposits, formed either out of undisplaced mineralizing solutions of a liquation origin, or in an accumulation of ore grains precipitated at an early crystallization stage of the mother magma.

F. Yu. Loewinson-Lessing did not think much of the importance of later residual mineralizing melts or of special pegmatite ore melts; he also regarded as of slight probability the formation of sizable ore bodies through the squeezing of the intercrystalline ore fluid from the newly-formed silicate crystals (filter pressing).

With regard to the Mt. Blagodat and Mt. Vysokaya deposits themselves, he believed that they combined magmatic and contact-meta-morphic mineralization with intrusive magmatic ore deposits being predominant in Mt. Blagodat, and the contact-metamorphic type in Mt. Vysokaya. He did not believe in the presence of a magmatic magnetite body at some depth under Mt. Vysokaya.

It is to be noted that these ideas of his did not become popular with the students of ore deposits. The venerable scientist himself did not insist on them, categorically. He wrote in 1937, two years before his death, "It seems to me that, at this stage of our knowledge, a solution of that problem, or some part of it, requires more than a critical analysis of literature, more than speculations, generalizations, and theoretical constructions. It requires new or revised field data, detailed and comparative studies of a number of ore deposits. Only such specific and accurate material will provide a basis for checking our theoretical concepts" (F. Yu. Loewinson-Lessing, "Magmatic Iron Ore Deposits". Trudy Konfer. po genezisu rud zheleza, margantsa i aluminiya. Izd. Akad. Nauk S.S.S.R., 1937).

In the following years, the Uralian iron-ore and copper contact-ore deposits were resur-veyed in detail, as they were in other areas of the Soviet Union. The fruitful theory of meta-somatic processes was developed, especially with regard to the formation of skarns and associated ores. Radical differences were de-termined between the Kiruna and Uralian con-tact-ore deposits; an epimagmatic (metasomatic) origin of ores and the enclosing skarns was

convincingly demonstrated for the Uralian localities.

A study of titanomagnetite deposits has shown an extensive development of ore incrustations in gabbro, peridotite, and pyroxenite, having a sid-eronite texture, and thus belonging to a fusion-type or ore deposits identified by A.N. Zavarit-skiy. A speparation of ore material at late stages of magmatic crystallization, rather than a liquation differentiation prior to crystallization was unquestionably established for them.

Just how the ore of massive injection bodies of titanomagnetite ores in gabbro becomes separated from the silicate magma remains conjectural, although in the last 20 years stu-dents have persistently regarded them as pro-ducts of crystallization of residual mineralizing melts or even as high temperature solutions. There still is no unanimity of opinion as to how a syenite (more generally granitoid) magma gives off volumes of mineralizing solutions capable of forming some of the largest contact-metamorphic deposits.

What is more, the path of study turns back to the ideas of a liquation differentiation of ore materials, now complemented by reaction of the magma with limestone and similar rocks, the so-called assimilation phenomena.

This idea was advanced by A.N. Zavaritskiy, long ago, with reference to the origin of the Mt. Vysokaya and Mt. Blagodat deposits, in his monograph on Mt. Magnitnaya. The same con-cept is advocated by L.N. Ovchinnikov recently, on the basis of experimental work and a study of the Mt. Vysokaya ores.

In working out concrete solutions for the origin of ore deposits, as stated in the quoted passage by F. Yu. Loewinson-Lessing, present-day students cannot afford to overlook his ideas on the differentiation of ore material out of a magma.

His pupils have contributed much also to the study of alkalic igneous rocks and associated ore deposits. In so doing, they enriched the science by identifying brand new types of ore concentrations of practical importance. Like the students working on the origin of magmatic-type deposits associated with basic rocks, they demonstrated that most commercial deposits of that type had been formed at a late rather than an early stage of the magmatic process proper, out of residual mineralizing melts.

It is well known that F. Yu. Loewinson-Lessing attached much importance to the syn-thesis of models reflecting natural processes and to the study of physicochemical conditions for magmatic and epimagmatic phenomena, as well as to the study of mineral systems under high temperature conditions.

In considering the magma as a complex solution, he insisted on experimental study of silicate systems with volatile components. He underscored the role of the volatiles at all stages of the magmatic process and particularly in the splitting off of the most volatile components and in the development of pneumatolytic phenomena.

The work of his pupil N. I. Khitarov is notable in this connection. He experimentally studied the formation of pure line rocks as the process of a consecutive transformation of basic magma, chiefly during the crystallization period, prompted by changing conditions with the presence of water the principal critical factor.

Until recently, there remained an open question as to the possible difference in the relationship between the main component, water and acid and basic silicate melts at high temperatures and pressures. The experimental results by N. I. Khitarov and his co-workers show that at 900°C and 3000 kgm/cm^2, the solubility of water in a basalt melt is almost 50% of that in a granite melt. An equalization of the water solubility in both melts is indicated at higher temperatures, despite the differences in chemical composition.

On the basic of his experimental study of the solubility of water in basic and acid melts, N. I. Khitarov demonstrated the peculiar features of water release as the magma proceeds toward the upper structural levels of lower temperatures.

A basalt melt tends to get rid of most of its solution water in deeper levels, while a granite melt shows the same tendency on upper levels.

As a magmatic melt cools, each time interval is characterized by a specific ratio of solid to liquid phases. The latter is progressively enriched by volatile and readily fusible components. Specific data on critical phenomena are essential for that stage of the magmatic process. The studies in this field, on aqueous solutions of inorganic substances, have shown that in the presence of a residual magmatic melt the critical phenomena occur in the same way as they do in a complex multi-component system.

The same studies have confirmed the existence of a "gaseous solution" of the non-volatile component in the volatile solvent (H_2O).

It has been demonstrated that in the presence of emanations with a simple composition containing silica, molybdenum, and water, the non-volatile emanation components are transported as complex compounds in a gaseous solution. In an alkalizing zone, a breakup of such complexes may lead to the formation of a close association of molybdenum and quartz. This carrying away of molybdenum by silica suggests

that standard volatiles such as boron, fluorine, chlorine, etc., are not necessary factors in a gas phase (pneumatolytic) mineralization.

Carbon dioxide is the second most common volatile component after water. Together with the latter, it controls the whole phenomena prevailing in natural solutions at higher temperatures. These two are the common components of liquid inclusions.

Special studies determined the relationship between temperature and pressure in water - carbon dioxide systems and provided data necessary for evaluating the pressures generated by such systems. The results of these experiments afforded the means of judging the phase state of relatively deep-seated thermal waters carrying carbon dioxide. These data are in fair accord with A. M. Ovchinnikov's views on the importance of hydrothermal carbon dioxide in mineralizing processes.

A progressive and consistent epimagmatic cooling leads to the appearance of hydrothermal solutions proper. The chemical nature of such solutions is approximately determined by the mineral composition of the hydrothermal formations themselves, with consideration given to the role of gaseous and readily soluble compounds ordinarily escaping the adjacent lateral rocks. The participiation of the latter cannot be accounted for, except by an indirect estimate - as is true for the physical composition itself, from a study of the chemical composition of liquid inclusions and from the changes in lateral rocks, brought about by reactions with the passing solutions.

A study of liquid inclusions has shown that inclusions in the quartz of quartz veins are the most concentrated; those in pegmatite minerals are less so; and those in granite minerals are the least concentrated. Present in them in various ratios are sulfates, chlorides, fluoride borates, bicarbonates of alkalies and alkaline earths, and also silica. Carbon dioxide and hydrogen sulfide have been identified among the gaseous components.

Special experimental studies of liquid inclusions have shown the substantial effect of the chlorine ion on the migration of lead, and the considerable migration capacity of the latter, higher than ordinarily inferred from the solubility of galena in water. The experiments have shown that these geochemical properties of lead are as characteristic for processes at great depth as they are for the shallow reaches of the crust.

Experimental data on the stability of galena show, at relatively low temperatures and pressures, that a superposition of chloride solutions on earlier ore accumulations is accompanied by a fairly intensive destruction of

primary ores and by a leaching of lead, with its subsequent dispersion or redeposition as younger ore concentrations (regenerated), depending on conditions. Such a redistribution of ore material is most common in sedimentary rocks.

The results of a series of experiments in model deep zones with geologic conditions adverse to a direct contact with heated up magmatic differentiates and favoring only heat transfer, have shown the possibility of hydrothermal solutions originating in sedimentary rocks, out of infiltration waters collected there. The hydrothermal solutions so originated beyond a direct contact with a magmatic source should be assigned to a special group of pseudomagmatic solutions.

These are, in a general outline, the results of work by N.I. Khitarov and his co-workers, on various aspects of endogenetic processes.

F. Yu. Loewinson-Lessing always underscored the conditional meaning of the term, "ore", by noting its dependence on engineering and economic factors. The present tendency is for the development of lean ores occurring in large bodies. His pupils have done much to encourage that trend. They have convincingly demonstrated, in the instance of alkalic rocks, that rocks themselves may constitute such ores, under conditions of easy exploration and thorough utilization. With each new year, alkalic igneous rocks become more important as sources of aluminum, phosphorus, niobium, titanium, zirconium, and other still rarer elements. The next to become commercially important undoubtedly will be greisen zones formed in autopneumatolytic processes, as a mass source of many elements essential in future technology. Finally, the time is not far off when derivatives of basalt magma will be commercially used.

ROLE OF ACADEMICIAN F.YU. LOEWINSON-LESSING IN THE DEVELOPMENT OF RUSSIAN EXPERIMENTAL PETROGRAPHY[1]

by

A. I. Tsvetkov

The name of F. Yu. Loewinson-Lessing is closely associated with the development of petrography of the native extrusive rocks. However, as witness the long list of his works, he also had a broad range of geologic interests. In addition, he touched upon problems in allied disciplines, such as chemistry, physics, metallurgy, technology of silicates, etc. He was especially interested in physicochemical petrographic experimentation. He regarded it as one of the most important methods of petrographic study and he maintained that although its application in other fields of geology is open to question or limited, it unquestionably presents an important means of solving problems of the origin and metamorphism of rocks ([21], p. 62).

At the same time he persistently warned against an unrestrained identification of natural processes with laboratory experiments. He stated in his paper read before the Third International Conference on Petrography and Mineralogy, in 1939, "A correct understanding of the petrographic significance of present-day experiments will be achieved by keeping in mind that they are performed on simple systems of a few components, mostly under rather low pressures and without a sizable amount of volatiles. It can be stated that most of these experiments do not satisfy the rule of similarity, so to speak. One should be, therefore, extremely careful in applying the results to complex processes taking place in nature's laboratory."

Because of the pressure of theoretical and organizational work, teaching, etc., F. Yu. Loewinson-Lessing did not have the time for systematic experiments of his own. Still, beginning as early as the nineties of the last century, he experimented on and off on such problems in petrogenesis as the fusion and crystallization of rocks, their solid-state transformations, the origin of magmatic minerals, magnetic phenomena in ores, etc.

His earliest experiments date back to his professorship of mineralogy in Yur'yev (Tartu) University, 1892-1902. At that time, he was busy on his famous thesis, "Studies in Theoretical Petrography In Connection With A Study of Central Caucasian Extrusive Rocks". Its gist is the familiar premise that a consideration of the physicochemical conditions is essential for a correct understanding of rock-making processes. He supported his theoretical studies with special experiments which he described in his thesis. His most interesting experiments on solubility of water in silicate melts belong to the same period; they determined its value to be 0.01% (at atmospheric pressure). These results were used by Rosebom, an outstanding physical chemist in his geologic interpretation of the theory of systems with volatile components (1904). F. Yu. Loewinson-Lessing also made numerous attempts to synthesize amphiboles out of a melt, in water vapor. Although his attempts were unsuccessful, they led him to the definite and correct conclusion that the presence of water was necessary for forming hydroxyl-carrying minerals out of a melt, and that consequently the melt should be under the proper pressure.

Thus even then F. Yu. Loewinson-Lessing attached great importance to water and other volatiles as essential components of a magma. In that, he was far in advance of his contemporaries, including those working at the Washington Geophysical Laboratory.

His idea of the mandatory presence of water in a magma for a crystallization of water-bearing minerals, including amphiboles, was corroborated first by D. P. Grigor'yev's modeling [7] of that process, with a substitution of hydroxyl by fluroine isomorphously replacing it; later on, it was corroborated by I. A. Ostroskiy [26] working at the former Institute of Geologic Sciences, the U. S. S. R. Academy of Sciences, who obtained hydroxyl-amphibole directly from a silicate melt in the presence of high pressure water vapor and hydrogen.

In determining the feasibility of magmatic differentiation by the specific weight of its

[1]Rol' akademika F.Yu Levinson-Lessinga v razvitii otechestvennoy eksperimental'noy petrografii.

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incipient crystals, F. Yu. Loewinson-Lessing placed crystals of leucite and augite in a silicate melt and obtained a concentration of leucite in the upper layer and of augite in the lower. However, these experiments, as the subsequent experiments by N. Bowen, although demonstrating the feasibility of crystallization differentiation, did not convince Loewinson-Lessing that it was the only possible mechanism of magmatic differentiation. While recognizing the importance of crystallization differentiation, he always remained a staunch advocate of magmatic differentiation. He supported the validity of the latter by field observations and by experimental data, after the above-mentioned experiments of Grigor'yev had demonstrated a definite stratification of melts.

Back at Yur'yev University he directly supervised the experiments of N. V. Kultashev [44], one of his assistants, on the $Na_2SiO_3 - CaSiO_3$ silicate system. That work, in addition to its own intrinsic value, is important in two other respects: it was the first physicochemical study of a silicate system in the world; and it was the first application of thermal analysis to the study of high-temperature equilibria in physicochemical systems. The A. Day and E. Allen [42] experiments at the Washington Geophysical Laboratory, often given priority in the study of silicate systems, were not published until 1905.

It is of interest to note in passing that, although thermal analysis of high temperature transformations was first used by G. Lechatelier as far back as 1886, it did not become a powerful tool in that field, until the turn of the century. A new impetus was given to it by our own famous scientist N. S. Kurnakov who demonstrated in 1901 that thermal analysis affords a means for determining the exact chemical composition of the components of a system, without their preliminary mechanical separation from other phases with which they are combined. Because of that, thermal analysis has become an extremely valuable method of studying phase equilibria in physicochemical systems, especially metal and salt. As such, it has become quite popular.

In 1902 F. Yu. Loewinson-Lessing was appointed Professor of Mineralogy at Petersburg Polytechnical Institute. That opened a new and long period of his scientific and teaching work in the future Leningrad. Naturally, the first experiments were carried on at the Institute, on a larger scale and with a greater number of assistants than in Yur'yev. Their main purpose was to study the phase equilibria in silicate systems in order to advance the capital problem of petrography, the origin of extrusive rocks. The following examples of that work are of note:

1) in cooperation with S. F. Zhemchuzhnyy [9], on reproducing porphyry textures in metal-salt melts, 1906; the data obtained were of interest in a physicochemical interpretation, by analogy with similar textures in certain igneous rocks.

2) a number of experiments by A. S. Ginzberg [2-5] on state diagrams for individual binary systems. In 1906 he studied the $CaSiO_3 - CaMgSi_2O_6$ system to find in it but a simple eutectic mixture. Thermal analysis was used in that study, now with the N. S. Kurnakov pyrometer invented in 1904. In 1908, he established a continuous series of solid solutions with a minimum of the fusibility curve, for a system of calcium and manganese metasilicates. In 1911, he obtained preliminary data on the anorthite-nepheline system and synthesized kaliophylite and eucryptite. The incomplete isomorphism of barium and calcium aluminosilicates was studied in 1915, along with the eutectics of solid solutions of extreme concentration in the $CaAl_2Si_2O_8 - BaAl_2Si_2O_8$ system.

3) P. I. Lebedev's studies [23] of eutectic dual systems, diopside-olivine and wollastonite-anorthite; also of various types of solid solution systems: $MgSiO_3 - MnSiO_3$, $CaSiO_3 - BaSiO_3$, and $CaSiO_3 - CaS$. The feasibility of forming solid solutions for sulfides in silicates was subsequently categorically denied by O. Glaser [43], J. Vogt [47], and W. Eitel [40]. It was not until recently that it was again demonstrated that solid solutions were indeed formed in Lebedev's system, pseudowollastonite-CaS, while the liquation in a liquid phase, particularly advocated by O. Glaser, was nonexistent [25, 39].

4) a series of works by A. Voloskov [1] on the phase equilibrium in a number of systems, silicate — sulfide and silicate — haloid;

5) experiments by N. S. Konstantinov and B. P. Selivanov [11] on the synthesis of calcium-ferruginous silicates, showing that hedenbergite cannot be obtained directly from the corresponding melt;

6) M. A. Usov's work on the $MnSiO_3 - FeSiO_3$ system [35] demonstrating that this system constitutes a trimorphous series; Fedorov's universal stage was first used in studying the products of this synthesis;

7) S. Smolenskiy's study of the silicate-titanite systems [32], etc.

A total of about twenty silicate systems were studied; it should be observed that the data from these studies (fusion temperature, transformation temperature, structure, etc.) have maintained their value to this day.

A detailed description of experimental works done under the direction of F. Yu.

Loewinson-Lessing at the Polytechnical Institute is given in a special review by S. F. Zhem-chuzhnyy and P. I. Lebedev [10].

Of the same period are F. Yu. Loewinson-Lessing's attempts [15] at the experimental explanation of certain aspects of metamorphism. In cooperation with B. V. Zalesskiy, he experimented with prolonged heating of minerals to determine their recrystallization in solid state. Serpentine samples were placed in the body of a blast furnace of the former Obukhov plant, where they were kept for several months at temperatures considerably below the fusion point. It turned out to be possible to achieve a mineral transformation by heat alone, without changing the mineral composition of the sample: the appearance of rhombic pyroxene, enstatite-augite, and olivine, in the experiments on serpentine.

With his eye on the same problem of metamorphism, earlier experiments were conducted by F. Yu. Loewinson-Lessing [14] on deformation in minerals and rocks (marble), at higher pressures; the effect of plasticity and brittleness of the samples tested was observed.

Of note is his extremely ingenious and productive experiment carried out in cooperation with A. K. Zaytsev [16] on pressure distribution in tunnels. It was performed on celluloid models. The birefringence appearing in the latter as a result of strain was readily measurable.

In recent years, Yu. A. Kosygin, I. V. Luchit-skiy, Yu. A. Rosanov [31], and I. V. Ginzburg and Yu. A. Rozanov [6] worked on similar problems at the Institute of the Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, the U. S. S. R. Academy of Sciences. Their experimental studies are a continuation of earlier works by F. Yu. Loewinson-Lessing.

A further development of petrographic and mineralogic experiments, in Russia in general and of those directed by F. Yu. Loewinson-Lessing was considerably slowed down by the First World War. They came into their own only after the Great October Socialist Revolution which marked the beginning of an ever-expanding organization of experimental centers at schools of higher education, research institutes, and industrial research organizations, and of an ever-growing volume of experimental work. F. Yu. Loewinson-Lessing actively participated in organizing some of these research centers. For instance, the Soviet of the Geological Committee (now VSEGEI) resolved, at his initiative in December of 1918, to set up a special laboratory of experimental petrography and mineralogy and assigned 100,000 rubles for that purpose. This laboratory, with D. S. Belyankin, an intimate assistant of F. Yu.

Loewinson-Lessing, as scientific consultant, has carried out a large number of study projects interesting both theoretically and practically. A 20-year survey of these projects (1918-1938) is presented by Kh. S. Nikogos'yan [24].

In 1929, F. Yu. Loewinson-Lessing founded an experimental laboratory in the U. S. S. R. Academy of Sciences, Geologic Museum, transferred subsequently to the U. S. S. R. Academy of Sciences Petrographic Institute and moved to Moscow, in 1934; it belongs now to the U. S. S. R. Academy of Sciences Institute of the Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry.

He participated in 1926 in organizing an experimental center at the Mining-Metallurgical Laboratory at Leningrad; and of the Physico-chemical Laboratory at the Leningrad Division of the Applied Mineralogy Institute. It was also at his suggestion that a course of experimental petrography was introduced in the Geologic and Pedologic Department of Leningrad University and an appropriate laboratory organized.

In addition to being an organizer and the inspiration of experimental work (his was the idea of periodic All-Union Conferences on Experimental and Industrial Mineralogy and Petrography, with three out of the five such conferences — 1934, 1936, 1939 — carried out under his direction), F. Yu. Loewinson-Lessing carried on his own experiments. To this period belong his most interesting experiments, in cooperation with V. F. Mitkevich and A. A. Turtsev [18, 20, 46] on magnetization of minerals and rocks, which provided material for a number of professional papers.

As pointed out before, he attached great importance to water in processes of magmatic crystallization. It must be stated that the study of silicate systems with volatile components, despite its importance in the theory of magmatic phenomena and metallogeny, has not been fully developed, either here or abroad. In the U. S. S. R., after the famed experiments of K. D. Khrushchov [41], the first definitely to synthesize hydroxyl-carrying minerals, this trend in experimental petrography and mineralogy was not resumed until the thirties and forties in this century.

That was the period of a number of successful works by F. V. Syromyatnikov on the synthesis of serpentine and on the gaseous transfer of silica [33, 34]; also N. I. Khitarov's and L. A. Ivanov's work on the critical temperature of aqueous solutions [36-38].

At F. Yu. Loewinson-Lessing's initiative, the U. S. S. R. Academy of Sciences, too, has undertaken the organization of a number of appropriate study projects. At the Petrographi

Institute, M. P. Volarovich has built a special installation for heating silicate and other materials, up to 1200 or 1300°C, in the presence of volatiles and at pressures up to 1000 atm. Heat was generated inside, while pressure was built up by outside compressors. That installation was used in a number of fruitful experiments at high pressures.

In the post-war years, this problem was attacked both theoretically and practically by I. A. Ostrovskiy, at the former Institute of Geologic Sciences, the U. S. S. R. Academy of Sciences. Like F. Yu. Loewinson-Lessing in his time, he started off with a synthesis of hydroxyl-bearing amphibole, under experimental conditions approaching as closely as possible the natural conditions of origin of this mineral in extrusive rocks. That synthesis, as we well know, was successful [26]. Subsequently, I. A. Ostrovskiy substantially expanded his studies to include the phenomena of general physicochemical equilibria in specific systems, along with a substantiation of theoretical premises concerning silicate-water systems, particularly in the limited miscibility of the liquid phase. The essence and the trend of these works by I. A. Ostrovskiy was a natural outcome of Loewinson-Lessing's studies of systems with volatiles, but carried out with new and much improved methods [27-30].

A characteristic feature of F. Yu. Loewinson-Lessing's works was his striving to apply them to practical problems of national economy. It is not an accident that it was he who developed the idea of an experimental study in the U. S. S. R., of manufacturing cast stone out of basalt, and it was he who promoted appropriate studies at the Mining and Metallurgical Laboratory and at the Division of Leningrad Institute of Applied Mineralogy.

It was undoubtedly the same desire to put science in the service of the national economy that prompted him in his long and effective work of organizing comprehensive, including experimental, studies of building stone in the U.S.S.R., and particularly at the U. S. S. R. Academy of Sciences. The Laboratory of Physical and Mechanical Properties of Rocks at the Institute of the Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry at the U. S. S. R. Academy of Sciences, successfully headed by B. V. Zalesskiy, is to some extent an offspring of F. Yu. Loewinson-Lessing.

He attached great importance to the petrographic study of products of the synthetic stone industry. He believed it to be of great assistance to the industry. He also believed that such products represented the results of a ready-made experiment whose initial material and conditions are well known; consequently, by studying these products, we may gain insight into natural processes of the origin and metamorphism of rocks. For that very reason, he regarded industrial petrography as a special branch of petrography. Personally, he could not give much of his time to the study of synthetic stone. That was done by D. S. Balyankin, one of his collaborators, who, together with his own pupils, has extensively and comprehensively investigated that field.

A brief article is inadequate, of course, to do justice to all the achievements of F. Yu. Loewinson-Lessing in developing native experimental petrography. It is, however, clear even from this abbreviated account that his influence was extremely beneficial. He not only obtained much valuable experimental data but, what is even more important, he succeeded in impressing geologists (petrographers) with the necessity of broad experimental study of the central problems in petrogenesis. He participated in organizing such studies and he guided their activity. It was only natural that, since the turn of the century, and to his last day, he stood at the head of a native school of experimental petrography.

We know now that experimental petrographic study keeps expanding in various institutions of the U. S. S. R. Thus, the work to which F. Yu. Loewinson-Lessing gave much of his effort, continues and grows.

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PHASE RELATIONSHIP IN PERIDOTITES
OF DAWROS (IRELAND) AND BELHELVIE (SCOTLAND)[1,2]

by

A. T. V. Rothstein

This paper considers the phase relationship of two groups of ultrabasic rocks: 1) Dawros (Ireland) and Belhelvie (Scotland). The equilibrium diagram has been constructed from published experimental data for silicate systems and natural mineral associations. Emphasis is put on the stability of the olivine-diopside-spinel association under certain magmatic conditions.

It is also noted that many different crystallization associations are possible within equilibrium diagrams for the forsterite-diopside-anorthite-silica system. The author concludes that phase relationship in these rocks corresponds to those in lime-alkali systems.

* * * * *

I believe it possible to construct equilibrium diagrams illustrating the new features in various associations of ultrabasic rocks. I am using for that purpose two ultrabasic series: the Dawros in Connemara (Ireland) and Belhelvie, near Aberdeen (Scotland). I regard peridotites from the northern Connemara as intermediate between peridotites of orogenic belts and deeper metamorphic zones (H. Hess, R. Howie, L. Wager [10, 11, 24] and the comparatively undisturbed peridotites of multilayer complexes (G. Brown, H. Hess, L. Wager and W. Deer, L. Wager [6, 9, 22, 23]).

The Dawros peridotites are intruded into sillimanite schist, strongly deformed in the vicinity of the ultrabasic bodies. In contrast, staurolite schists to the south and the less metamorphosed schists to the north have not been deformed to the same extent. Detailed field and mineralogic observations show that the peridotites were intruded as a hot but solid body, with a resulting hornfelsitization, intensive deformation, and a partial mylonitization of the enclosing schists.

These peridotites occur in the northern segment of the Connemara anticlinal structure (A. Rothstein, [17]). Despite their limited size, they possess a number of typical features reflecting their intrusive origin. They belong to the Connemara series of basic igneous rocks (L. Ingold, B. Leake, [12, 13]) intruded in crystalline schists during an orogeny. They were subject to dynamic stresses at high temperatures, at a late stage of regional metamorphism and were cut by gabbroid bodies, subsequently epidotized.

The original peridotite massif apparently was lenticular; subsequently it was deformed, broken up, and its segments were displaced. It was probably larger, to start with; then the upper layer of feldspathic rocks may have been removed during the deformation. However, no feldspar has been found in peridotites exposed in the present erosional surface.

The peridotite massif is fringed by massive harzburgite and pyroxenite, while its core consists of alternating dunite and pyroxenite with transitional harzburgite and lherzolite varieties.

In those parts of the Dawros massif most affected by dynamic metamorphism, the bulk of primary mineral accumulations are recrystallized to a metamorphic mosaic of olivine and pyroxene. These recrystallized minerals generally differ little from the primary igneous minerals. Still, preserved here and there are unaltered rocks with evidence of a primary accumulation of minerals, which sheds light on their origin. I find it interesting that there is evidence here of a magmatic origin for a group of ultramafic rocks.

Ultramafic rocks of Dawros are stratified as the result of a rhythmic accumulation of olivine, magnesial orthopyroxene, chromespinel, and

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diopside clinopyroxene. They carry no feld-spar;[3] in this peculiar feature, they are sim-ilar to the orogenic belt peridotites.

The Dawros ultramafic rocks belong to two principal groups — harzburgites and lherzolites. Most interesting is the central stratified body, varying from harzburgites at the base to lherzolites on top. Occurring near the base are thick beds of dunite with occasional thin pyro-xenite intercalations; in the upper part, the pyroxenite layers are thicker while the dunites are thinner and less numerous. Present in a transitional zone between the harzburgite and lherzolite layers is a layer rich in chrome-spinel (traceable all along the trend of the in-trusion) and a series of wehrlite rocks.

are exposures of massive peridotite with in-clusions of dunite, harzburgite with clots of rhombic pyroxene, and massive bronzite pyro-xenite.

In several localities, peridotites are exposed within the schists. It is possible that they were related petrographically to a formerly single peridotite massif, subsequently broken up. A wehrlite horizon is fairly well developed in the northern part of the massif (between points U and V, Figure 2). Traceable here in banded bedrock exposures (Figure 1) is the entire transition from harzburgite (α) through wehrlite (β) to lherzolite (γ). This sequence is impor-tant because it is typical of the entire intrusion.

FIGURE 1. Diagrammatic sketch of an outcrop of stratified ultramafic rocks.

α - harzburgite; β - wehrlite; γ - lherzolite.

Several bands of hypersthene and spinel rocks have been observed among the harzburgite layers. Within the central body, this mineral banding has a predominant northwest-southeast trend with variable northeasterly dips. The primary banding exhibits a variety of relations with the enclosing rocks.

The northeastern boundary of the massif is conformable with the outer contact and the strike of the Connemara schists; the western boundary is unconformable, with remnants of hornfelsitic and slightly mylonitized enclosing rocks. Located along the southwestern margin

The mineralogic map of the largest peridotit body (Figure 2) illustrates the wide range of types whose essential features are common to the whole. This map best reflects the incon-sistency in the content of rhombic and mono-clinic pyroxenes in rocks of the banded and the undifferentiated portions of the intrusion. Note the considerable extension of the spinel horizon. The letters refer to locations mentioned in the text.

A detailed survey of mineralogic data is found in our earlier work [17]. Here we only note that both vertical and horizontal correlati is possible because of the definite mineralogic regularities determined for ultramafic rocks of Dawros. There is a definite sequence in the alternation of mineral associations, and a tran sition from the olivine + rhombic pyroxene

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[3] For this reason the Dawros rocks have been assigned to the ultramafic group.

FIGURE 2. Mineralogic map of the main body of Dawros peridotite

1 – association CLP + OP; 2 – CLP, OP missing; 3 – OP, CLP missing; 4 – OP predominant, CLP subordinate; 5 – CLP predominant, OP subordinate; 1 – 5 – rectangles designate banded rocks: CLP, to the left; OP, to the right; squares designate nonbanded rocks: CLP, at the top; OP, at the bottom; 6 – hypersthene pyroxenite; 7 – chromespinel horizon; 8 – massive pyroxenite (OP); 9 – massive harzburgite; 10 – talcose pyroxenite veins; 11 – boundaries of peridotite; 12 – epidiorite schist; 13 – faults; 14 – (α) extrusive igneous textures predominate; (β) metamorphic textures predominate (brought about by recrystallization); 15 – marked points; 16 – relief outlines; 17 – walls and fences; 18 – buildings.
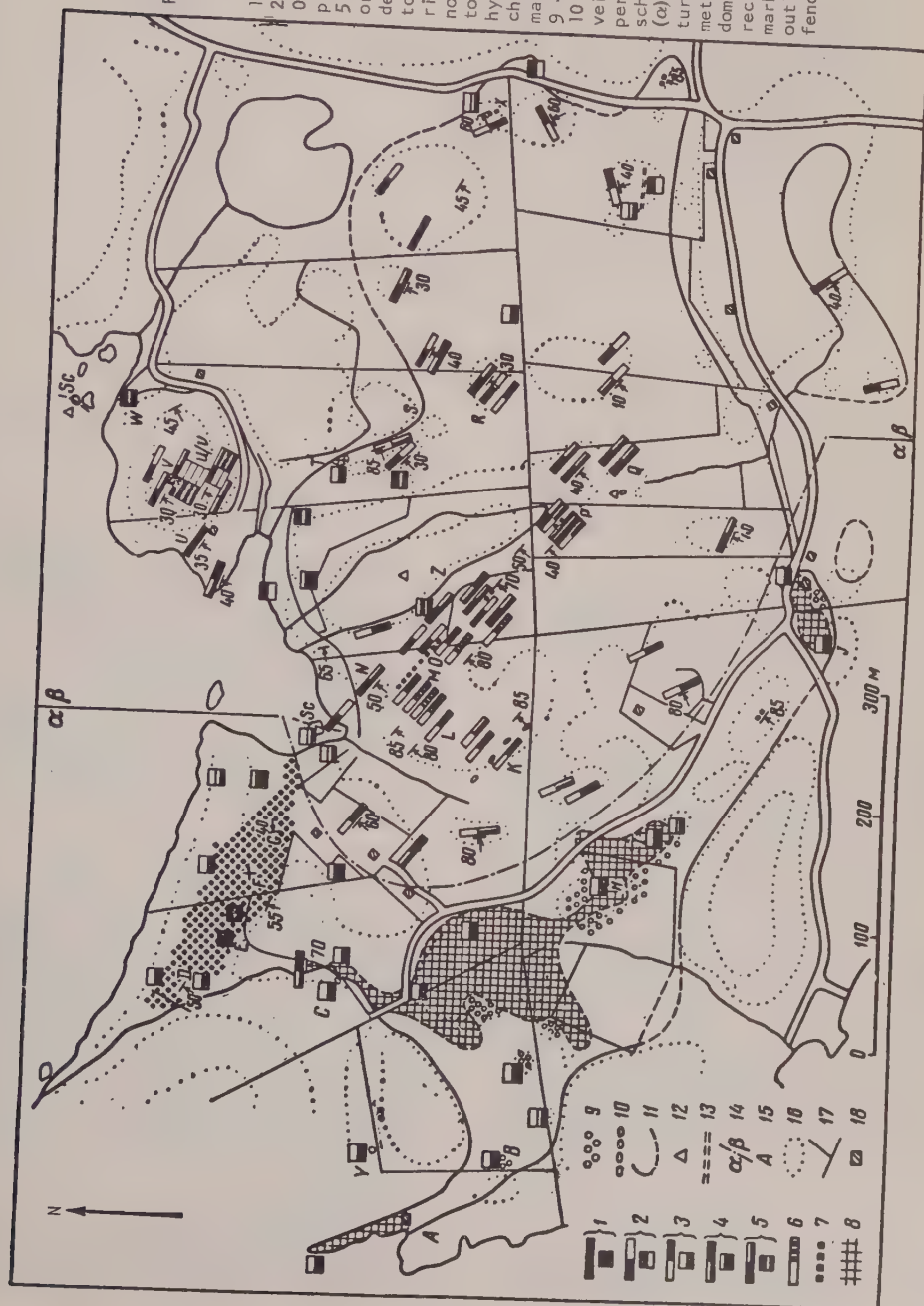
Table 1

Vertical sequence of mineral associations

Olivine + monoclinic pyroxene + small amount of rhombic pyroxene. Primary CLP: Ca45, 1·Mg47.5·Fe7.3	N[1]
Olivine + monoclinic pyroxene + semitransparent green spinel (this horizon has not been observed in all outcrops)	—
Olivine + chromespinel ± rhombic pyroxene ± monoclinic pyroxene. Recrystallized pyroxenes (CLP, OP): Ca44.9·Mg50·Fe5.1; Ca1.0·Mg85.6·Fe13.4	R
Olivine + rhombic pyroxene ± subordinate clinopyroxene. Primary OP: Ca1.8·Mg86.8·Fe11.3 (sampling locality P)	P, I
Olivine + rhombic pyroxene. Recrystallized. OP: Ca1.2·Mg90.3·Fe8.5 (sampling locality L)	M, L
Olivine + small amount of rhombic pyroxene	—
Olivine	—

[1] Letters designate the sampling locations for analyzed pyroxenes (see Figure 2 and Table 2); OP — rhombic pyroxene; CLP — diopside.

association to the olivine + monoclinic pyroxene association with subordinate rhombic pyroxene (Table 1).

The total thickness of the section corresponding to this stratigraphic column is about 153 m, with about 107 m of olivine-rich rocks; not over 30 m of harzburgite; and less than 15 m of lherzolite.

The vertical sequence of mineral associations is complicated by many details, as seen in the map (Figure 2); for this reason, it is necessary to summarize their main features. That has been done in more detail in our other work [17].

The slight differences in the composition of pyroxenes themselves (Table 2) have been brought about by a later high-temperature recrystallization, as shown by a detailed study of pyroxenes from the Dawros massif.

Figure 3 shows the relationship between mineral associations and banded rocks of the central core (right) and massive facies of the southwestern margin of the massif (left). The chromespinel horizon occurs approximately at the level of the horizontal line connecting the two columns.

We shall pause in more detail on the vertical sequence of these rocks (Figure 3); H, C, P, U/V, V are sampling locations, Figure 2).

MASSIVE PERIDOTITES OF THE MARGINAL PART

H. Massive harzburgite: large crystals of primary bronzite with inclusions of resorbed olivine; microscopic lamellae of exsolved monoclinic pyroxene in bronzite; the small olivine inclusions in bronzite are very slightly resorbed and have euhedral outlines.

C. Massive pyroxenite: primary bronzite tablets contain lamellae of monoclinic pyroxene, with no olivine observed; this suggests primary precipitation out of solution.

BANDED ROCKS OF THE CORE

P. Banded harzburgite: coarse crystals of primary rhombic pyroxene with lamellae of exsolved diopside pyroxene and possibly including partially resorbed olivine. Most of the smaller crystals have been formed in the recrystallization of the larger ones. Two small tablets of monoclinic pyroxene (right) also interstitial olivine (nearer to the center) are visible. Rhombic pyroxene has been formed most likely in a reaction with olivine as well as by primary precipitation.

U/V. Banded wehrlite: this rock contains monoclinic pyroxene, olivine, and semitransparent spinel; the texture mostly primary, having originated in a simultaneous crystallization
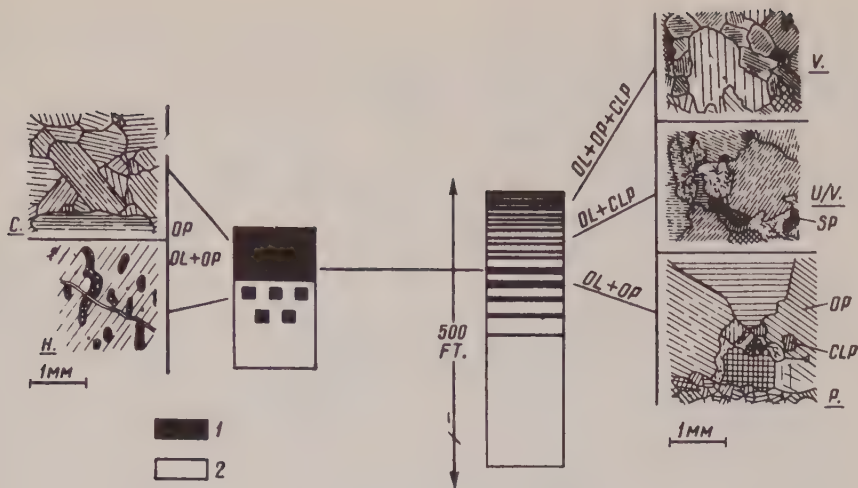
FIGURE 3. The sequence of mineral associations in the
dunite-peridotite-pyroxenite complex.

1 - pyroxenite; 2 - dunite.

of these minerals. Pyroxene carries spinel,
euhedral to subhedral, of the same variety as
in its irregular interstitial inclusions.

V. Banded lherzolite: relicts of primary
pyroxenes in a mosaic of recrystallized mate-
rial. Recrystallized pyroxenes are free of
lamellae of monoclinic and rhombic pyroxene
(former solution), while they are present in
primary pyroxenes. A few olivine grains have
been observed along with some opaque ore. A
distinctive feature of this rock is the reappear-
ance of primary rhombic pyroxene with lamel-
lae of monoclinic pyroxene, completely missing
in the underlying wehrlites.

The crystallization assimilation process in
Dawros is demonstrated in the chromespinel
horizon. It shows evidence of the combined
action of magmatic currents and gravity pre-
cipitation, in "wedging-out bands"; also of a
density stratification in the precipitation of
chromespinel and olivine. A rhythmic mechani-
cal sorting, too, could have produced the banding
effect. It is possible that a proof of the rhyth-
mic deposition lies in the "reverse" gradation
of the chromespinel grains, most likely as a re-
sult of crystallization not far away from the ac-
cumulation points, under conditions of a quietly
flowing magma. The sudden precipitation of
some fine-grained spinel at the base of chromite
layers is most likely due to new crystallization
centers (L. Wager, [25]). The monomineral
spinel concentrations apparently required a
mechanical separation from olivine, although
we shall later discuss another way of forming
monomineral rocks. A careful study of examples

were the spinel-olivine separation is incomplete
reveals a simultaneous change in the olivine
grains, as well, the change proceeding toward
the top of the spinel-olivine rhythmic unit.

Thus, the rhythmic emergence of new crys-
tallization centers, if it took place at all, al-
most simultaneously embraced these two phases,
with some period of magma mobility necessary
for their complete differentiation into opposite
layers. The less conspicuous stratification in
olivine-diopside rocks of this intrusion could
have been the result of mechanical sorting, in-
volving two minerals with specific weights much
lower than those of olivine and chromespinel.
However, the olivine-enstatite rocks are de-
finitely banded, although perhaps as the result
of a rhythmic crystallization of alternate phases.
In that event, the crystallization would have
taken place near the olivine-enstatite peritectic
point (H. Bowen and D. Andersen, [2]).[4]

The northwestern part of the chromespinel
horizon (Figure 2) is accompanied by coarse-
grained pyroxenite consisting of accumulations
of very large "pegmatitic" crystals. Some of
these accumulations are represented by mag-
nesial orthopyroxenite; the others - by diopside
clinopyroxenite; while some others carry both

[4] After the completion of this work, an interesting
example of rhythmic crystallization in rocks of an
ultrabasic sill was published (Weedon, D.S., The
Gars-Bheinn Ultrabasic Sill, Isle of Skye. Quarterly
Journ. of the Geol. Soc. of London, vol. 116, 1960).

Table 2

Chemical Analyses of Pyroxenites (in %)[3]

Sampling locations	L	P_1	P_2	I	R	R	N	M	4645	R
Type[1]	OP	OP	OP	OP	OP	C_L^P	C_L^P	OP	OP	R
Origin of pyroxenites[2]	R	P	R	P	R	R	P	M	–	Analysis of rock
SiO_2	57.10	55.70	55.11	56.25	55.02	52.73	51.81	50.14	51.69	51.30
Al_2O_3	0.70	1.87	2.28	2.45	2.69	2.05	3.60	6.02	4.55	1.74
Fe_2O_3	0.60	1.13	1.03	1.07	1.81	1.00	1.08	1.83	0.55	2.38
FeO	5.21	6.47	6.52	7.15	7.18	2.37	3.48	15.38	16.51	5.32
MgO	34.52	32.72	32.98	32.38	32.13	18.05	16.77	24.58	25.74	27.36
CaO	0.62	0.95	0.82	0.83	0.48	22.57	22.13	0.30	0.50	8.44
Na_2O	0.07	0.05	0.04	0.14	0.02	0.16	0.21	0.06	0.03	–
K_2O	0.03	0.01	0.01	0.04	0.01	0.01	0.02	0.05	0.02	–
H_2O^+	0.64	0.26	0.36	–	0.21	0.48	0.24	0.18	0.04	2.42
H_2O^-	0.06	0.07	0.03	–	0.02	0.09	0.04	0.06	0.05	0.12
TiO_2	0.17	0.10	0.10	0.22	0.12	0.25	0.21	1.05	0.15	0.44
Cr_2O_3	0.27	0.44	0.29	–	0.34	0.43	0.38	0.26	–	0.34
MnO	0.17	0.15	0.16	0.16	0.19	0.12	0.11	0.36	0.27	0.15
NiO	0.04	–	–	–	–	0.03	–	0.05	–	–
Total	100.20	99.92	100,13	100.69	100.22	100.33	100.08	100.32	100.10	100.01
Ca	1.2	1.8	1.5	1.6	1.0	44.9	45.1	0.6	1.0	
Mg	90.3	86.8	87.3	86.2	85.6	50.0	47.5	71.2	71.9	
Fe	8.5	11.3	11.2	12.2	13.4	5.1	7.3	28.2	27.1	

% Al₂	1.3	2.9	3.3	3.2	4.1	3.2	4.8	9.1	5.3
γ[OP] β[CLP]	1.674±0.001 / —	1.680±0.002 / —	—	—	1.683±0.001 / —	1.679±0.003	1.684±0.001	1.704±0.004 / —	1.690 / —
2V	+74±2°	+83±1°	—	—	+87±1°	+55±1°	+55±1°	−76±1°	−76°

[1] OP – rhombic pyroxene. CLP – diopside.

[2] P – primary, R – recrystallized, M – metamorphic.

[3] Sampling locations are indicated in Figure 2. It is assumed that the analysis of rock R represents a typical composition of ultrabasic rocks in the massif. Analyses L, P, R, N, and M, by E.A. Vincent; I, by B.A. Collet and E.A. Vincent; R, by R.A. Hall, of the Geology Department Laboratory, Oxford University. Analysis 4545 borrowed from R. Howie [11].

Ratio Ca:Mg:Fe computed by the Hess method (H. Hess, Chemical Composition and Optical Properties of Common Clinopyroxenes. Part I. Amer. Min., vol. 34, 1949).

varieties. The coarse rhombic pyroxenes often carry a considerable amount of chromespinel with occasional evidence of magmatic corrosion. Spinel is quite rare in diopside pyroxene; what is interesting, however, is that spinel in such inclusions is perfectly euhedral. This is quite surprising, considering that the two minerals have crystallized out of a normal melt, in the diopside-forsterite-anorthite system (E. Osborn and D. Tait, [14]).

Coarse rhombic pyroxenes of these accumulations often carry rounded olivine crystals; as a consequence, they lose their similarity to the marginal accumulations of orthopyroxene tablets. However, these marginal pyroxenes overlie a massive harzburgite with sizable poikilitic tablets of rhombic pyroxene carrying a partly resorbed olivine. It seems as though the marginal rock melt at one time passed the olivine-pyroxene peritectic point, while crystallization in the central banded core was more complex and was marked by fluctuating conditions. The important thing is that the melt could have passed such a peritectic point, whatever the true conditions. This indicates that a melt does not have to be undersaturated in SiO_2. This inference is inadequately expressed in the "ultrabasic" melt concept.

It also is of interest that marginal pyroxenites and harzburgites, almost completely unaffected by the subsequent recrystallization, do not carry any interstitial feldspar. Biotite alone, occasionally present in small flakes, appears to be of a later origin than the primary chromespinel, olivine, and rhombic pyroxene. All other minerals are secondary, being related to serpentinization. I regard as unusual the absence of feldspar in these massive marginal pyroxenites and harzburgites, in the event that a normal saturated basalt melt was the one to crystallize. However, the absence of diopside clinopyroxenite in these harzburgites and pyroxenites, and its presence in some other segments of the intrusion, suggests a strong selective process in the formation of these rocks.

The main process of the crystallization accumulation is accompanied by a progressive change in the nature of the layers precipitated. There is a continuous change from the olivine + orthopyroxene association to the olivine + diopside + subordinate orthopyroxene association, marked by a chromespinel horizon and wehrlite series, at the point of change between these two systems. It is possible that this is the point of change for alternating associations. These variations are related to the changes in solid solutions of the minerals themselves, from high- to low-temperature blends.

Table 2 presents the chemical analyses and optical properties of the Dawros massif pyroxenes. They show, despite certain fluctuations, including those caused by crystallization

phenomena, that the Mg/Fe ratio in orthopyro-xenes ranges from 10. 6 to 6. 4, with only a 6. 5 to 9. 8 range for diopside pyroxenes. It is probable that changes in the iron oxidation state (W. Ernst, [8]) could have induced the Mg/Fe ratio fluctuations, as well; but it re-mains to be demonstrated that the pyroxene associations themselves would have been modi-fied, at the same time. Important experimental work has been carried out recently on the system $MgO - FeO - Fe_2O_3 - SiO_2$, with momentous re-sults (E. Osborn, [15]). However, the system $MgO - CaO - FeO - Fe_2O_3 - SiO_2$ is more com-plex. The "cryptic variation" ([23], page 336) in Dawros rocks has been accepted as evidence of a fractional crystallization at falling tem-peratures. It should be noted that the Dawros pyroxene series (A. Rothstein, [18]) is located at the front of a normal pyroxene sequence in the crystallization of a saturated basalt magma (G. Brown, E. Osborn, E. Poldevaart and H. Hess, [7, 15, 16]).

A curious sequence prevails between bronzite and diopside in layered rocks of Dawros. In those parts of the intrusion with wehrlite series, rhombic pyroxene temporarily disappears. In-asmuch as the minerals are represented by olivine and the two pyroxenes, their phase re-lationship appears to be quite similar to the diopside-forsterite-silica system (N. Bowen, [3]). Certain aspects of the pyroxene sequence may be interpreted by analysis of the liquidus-solidus-solvus of that system, but this is not true for some other aspects. The true transi-tion from harzburgite and wehrlite toward pyro-xenite occurs at different points; this may be explained by the minimum of the liquidus located in the direction of diopside, at the solidus-solvus intersection of the enstatite/diopside section (J. Schairer and F. Boyd, [21]). This, however, does not explain the presence of olivine in wehrlite, nor the subsequent re-version to lherzolite rocks.

Figure 4 illustrates the ternary diopside-forsterite-silica system [3], with different liquidus-solidus-solvus ratios possible along the enstatite/diopside section.

Figure 5 presents a possible enstatite/ diop-side section (after N. Bowen, [3]; J. Schairer and F. Boyd, [21]). The crystallization se-quence in this system is as follows: olivine → enstatite → enstatite + diopside → diopside. It corresponds to the lower harzburgite portion of Dawros but does not explain the presence of wehrlite (olivine + diopside) nor of the over-lying lherzolites (olivine + diopside + enstatite).

It is possible that deviations in the phase boundaries occurred because of water vapor under high pressure. I cite here the following quotation:

"Yoder has set forth the results of his latest study of fusibility at water vapor pressure in the diopside-anorthite system, which is the basis for the study of basalt. His was a parti-cularly great contribution because of his dis-covery of a considerable displacement in the eutectic composition with a rise in the water vapor pressure. This displacement can be applied to the problem of layered laccoliths" ([19], page 218).

I believe it would be interesting to obtain more accurate data on the forsterite-diopside-silica-water system. While the effect mention-ed above partly explains the sequence of forma-tion for Dawros rocks, another system may pro-vide a better explanation.

In view of the increase in the iron content in pyroxene, it is quite possible that the Dawros rocks are better represented by the forsterite-fayalite — diopside — silica system (after N. Bowen and J. Schairer, [3]; N. Bowen, [4]).

Figure 6 presents such a system. By pro-jecting the experimentally known phase relations in borderline conditions, we can determine the
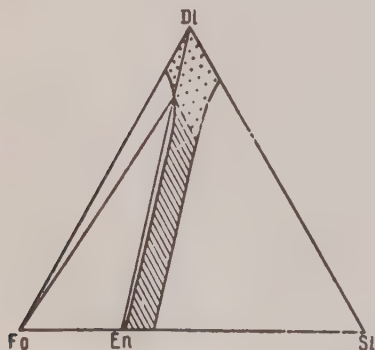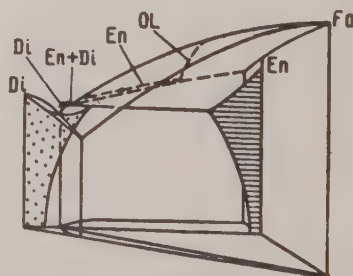

FIGURE 4. The ternary system diopside-forsterite-silica

Dots — diopside crystallization field; hachures — enstatite.

FIGURE 5. The liquidus-solidus-solvus relationship in the En/Di cross section (see Figure 4).
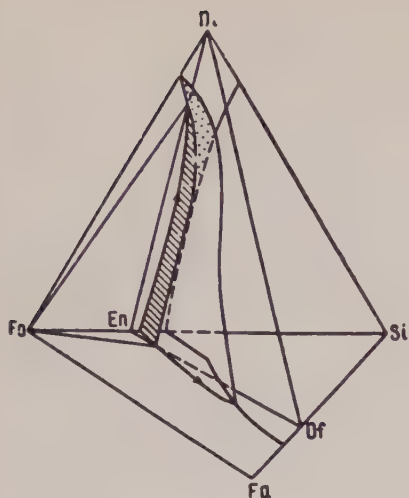
FIGURE 6. The quadruple system
Fo - Fa - Di - Si

For simplicity, line Di - Fa is
omitted.

relations between the forsterite/fayalite, en-
statite/orthoferrosilicate, diopside and silica
phases, as indicated separately in Figure 7
which illustrates the olivine/pyroxene boundary
surface and the sequence of primarily precipi-
tated minerals in Dawros. This not only corre-
sponds to the crystallization sequence of a melt
but also identifies the minerals precipitated
(for details on see N. Bowen and J. Schairer,
[4]).

The pyroxene sequence at Dawros can be

explained by an analysis of the curved crystal-
lization path (Figure 7) at the olivine/pyroxene
boundary surface, within this system. That
path passes through the harzburgite segment of
the olivine/pyroxene, after the crystallization
of the basalt dunite, then continues to the
wehrlite segment, and back again to the point
where olivine and the two pyroxenes are pre-
cipitated. This surface is interesting because
the olivine/pyroxene reaction ratio is partially
missing in it, including the portion in the vicinity
of diopside. Figure 8 shows that pyroxenes as-
sociated with this boundary surface (Figure 7)
correspond to the first part of the saturated
basaltic magma series (G. Brown, A. Polder-
vaart and H. Hess [7, 16]).

The appearance of the olivine-diopside-
aluminospinel association in the wehrlite group
can be explained by crystallization of a fluid in
the diopside-forsterite-anorthite-silica system,
under the conditions of occurrence for the
diopside and spinel flields. Here I quote E.
Osborn and D. Tait:
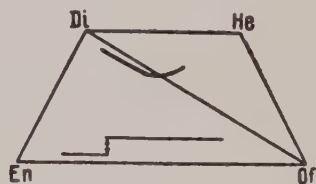
FIGURE 8. Triangle of composition
En-Di-Of (Figure 6) plotted on the
composition diagram for pyroxenes, after
A. Poldervaart and H. Hess.

FIGURE 7. The olivine - pyroxene
boundary surface
(Figure 6)

"Forsterite, anorthite, and spinel, or
forsterite, anorthite, and pyroxene can coexist
at temperatures above the solidus; but pyroxene
and spinel are not compatible. However, field
and laboratory studies of troctolite and associ-
ated coronite suggest that the reverse is true;
at lower temperatures, spinel and diopside are
compatible under equilibrium conditions, while
lime plagioclase and olivine are incompatible.
For this reason, at a somewhat higher tem-
perature an accumulation of lime plagioclase
and of magnesium olivine crystals becomes a
metastable association; under favorable condi-
tions it changes to a stable low-temperature
association of pyroxene, spinel, and plagio-
clase or pyroxene, spinel, and olivine. Thus
the experiments show that at both high (approxi-
mately above $1320°$) and low (below $90°C$) tem-
peratures, lime anorthite and magnesium
olivine constitute a metastable association, al-
though they can coexist in equilibrium at inter-
mediate temperatures" ([14], page 432).
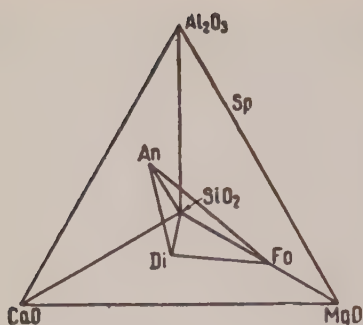
FIGURE 9. The position diagram for the diopside-anorthite-forsterite-silica system, in the four-component $CaO-Al_2O_3-MgO-SiO_2$ system.
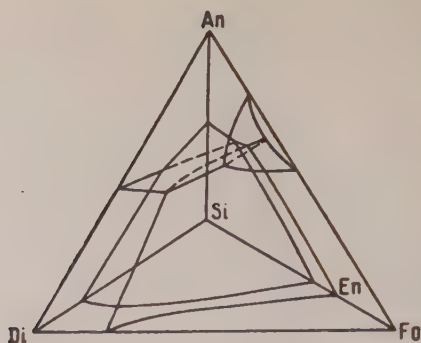
FIGURE 10. Position of a monovariant section in the diopside-anorthite-forsterite-silica system.

I believe that rock textures and field observations at Dawros (A. Rothstein, [17]) indicate that wehrlite has crystallized directly out of a melt. Should these two fields (pyroxene and spinel) have come together in the crystallization of Dawros magma, their phase relations would have been as shown in Figures 9-14 (based on the E. Osborn and D. Tait diagrams, [14], page 426). They illustrate in a simplified way some of the phase relations in the lime-alkali system.

The diagram in Figure 12 presents the phase relations in the forsterite-anorthite-diopside-silica system. Shown here are the enstatite and diopside fields of the olivine/pyroxene boundary surface as well as the spinel field. As we see, the spinel field does not intersect this boundary surface; therefore feldspar-free diopside-spinel rocks may not be anticipated. However, the Dawros wehrlite is just such a rock.

Figures 13 and 14 illustrate the changeable

relations between the spinel and pyroxene fields in the Fo — Di — An system. Figure 13 presents normal phase relations, while Figure 14 presents the less common ones. It is possible

FIGURE 12. Phase relations in the diopside-anorthite-forsterite-silica system.

that some high pressure conditions are necessary for the second type. In Dawros wehrlite, this may be due to water vapor pressure, which most likely also lowers the crystallization temperature.[5]

FIGURE 11. Phase boundary surfaces marked on diagram by the author.

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[5] Not considered here is a possible expansion of the spinel field in the presence of Cr_2O_3 in the magma.
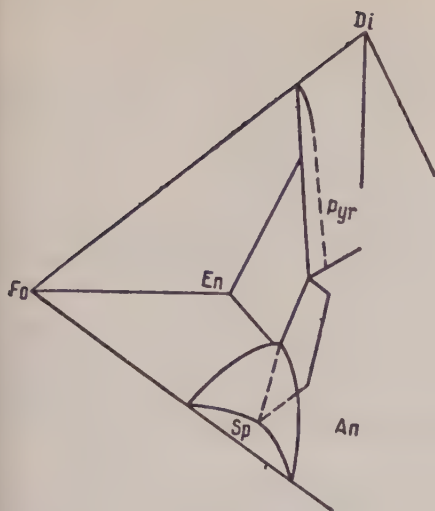
FIGURE 13. Normal phase relations
in the Fo – Di – An – Si system.
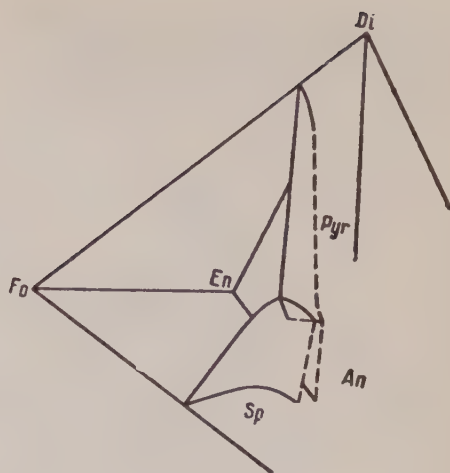
FIGURE 14. Anomalous phase relations
in the Fo – Di – An – Si system.

In Dawros, minerals of the olivine-diopside-spinel association most probably belong to the monovariant line and the course of the crystallization is such as to displace the melt backward, toward the olivine — two pyroxene conditions.   The direct result of a deterioration in the spinel reaction conditions would be a melt migration along the olivine-diopside boundary surface.   Wehrlite textures show strong evidence of a contemporaneous crystallization of olivine and diopside, while green spinel is subhedral when occurring in pyroxene; and with extremely irregular outlines when occurring outside it.

The appearance of coarse-grained pyroxenites in the harzburgite and lherzolite groups may mean an invasion of the pyroxene field by the melt, because olivine did not enter the reaction so that the melt composition remained, as before, on the olivine/pyroxene boundary surface.   Such a possibility is not realized in wehrlite, although the exclusion of spinel from the reaction would have been one of the concrete ways of precipitating rhombic pyroxene.

The specific features and sequence of Dawros rocks possibly suggest that the melt crystallized in acccordance with the forsterite-diopside-anorthite-silica system, but under unusual conditions.   For a deeper and better insight into the phase diagrams, their application is considered for another series of ultrabasic rocks, namely the Belhelvie, near Aberdeen, Scotland (F. Stewart, [20]).   The Belhelvie intrusion is postorogenic and is a stratified complex.   Figure 15 illustrates the main sequence of rocks, from west to east across

the complex.   Participating in this intrusion are diverse rocks such as dunite, enstatite-augite peridotite, pyroxenite (enstatite + augite), troctolite, anorthosite, olivine norite, olivine-hypersthene gabbro, norite, hypersthene gabbro, and olivine gabbro (nomenclature after F.

Olivine gabbro	Olivine gabbro, hypersthene gabbro
Norite	Olivine norite, norite, olivine-hypersthene gabbro, hypersthene gabbro
Troctolite	Dunite, troctolite, anorthosite
Peridotite	Dunite, enstatite peridotite, enstatite-augite peridotite, augite peridotite, pyroxenite (enstatite + augite)

FIGURE 15. Cross section of the
Belhelvie complex; peridotites in
the west, gabbroid rock in the east.

Stewart, 1947).   The peridotites carry a small amount of plagioclase.   The olivine/pyroxene reaction ratio is important in these rocks because they carry rhombic pyroxene in both poikolitic tablets and in leists free of olivine. The same ratio probably determines the change of troctolite to norite; such a sequence has been shown for the forsterite-anorthite-silica system

(O. Andersen, [1]) which is one of the marginal ones in the forsterite-diopside-anorthite-silica system. The many varieties of Belhelvie intrusive rocks, plotted in Figure 16, have a definite place in that system.[6]
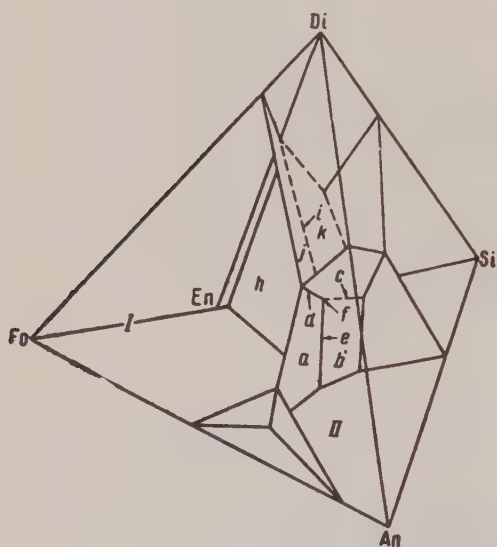
FIGURE 16. Diagram of the Fo - Di - An - Si system; phase relations of ultrabasic rocks.

It appears then that the several rocks can be considered in the following relationships:

1. Dunite is equivalent to olivine field I.

2. Enstatite peridotite is equivalent to the olivine/enstatite boundary surface Ih.

3. Enstatite-augite peridotite is equivalent to the two pyroxenes line on the olivine/pyroxene boundary surface Ii.

4. Augite peridotite is equivalent to the olivine/diopside boundary surface Ij.

5. Enstatite-augite pyroxenite is equivalent to the surface of the two pyroxenes within the pyroxene field k.

6. Troctolite is equivalent to the olivine/anorthite boundary surface IIa.

7. Anorthosite is equivalent to the anorthite field II.

8. Olivine norite is equivalent to the olivine/anorthite/hypersthene line IIe.

9. Olivine-hypersthene gabbro is equivalent to the olivine/anorthite/hypersthene/diopside point IIf.

10. Norite is equivalent to the hypersthene/anorthite boundary surface IIb.

11. Hypersthene gabbro is equivalent to the hypersthene/anorthite/diopside line IIc.

12. Olivine gabbro is equivalent to the olivine/anorthite/diopside line IId.

Also noticeable in this diagram is a gabbro field at the anorthite/diopside boundary surface

It is of interest that the melt with a crystallization trend toward composition (f), as for instance from the olivine field, could have produced all these rocks, with only a small change in its position with relation to the phase boundaries.[7]

I believe that these diagrams, although simplified, shed light on the true aspect of actual relations prevailing in ultrabasic rocks. It is my opinion that the original melt of Dawros rocks possessed all the properties corresponding to both the forsterite/fayalite/diopside/silica and the forsterite/diopside/anorthite/silica systems, but these properties were manifested under unusual conditions. It seems to me that such conditions, in all their aspects, may be assumed to be those of a saturated basalt magma in an "ultramafic magmatic stage". The high water vapor pressure should have led to a solidus-solvus depression in the enstatite-diopside section, in order to produce the actual pyroxenes, both rich and poor in calcium, instead of those pyroxenes which could be anticipated in sections observed in a dry system. In studying the $MgSiO_3$ and $CaMgSi_2O_6$ system, Schairer and Boyd [21] have discovered that the solvus crosses the solidus, i. e. , there is no such thing as a $MgSiO_3$ and $CaMgSi_2O_6$ solid solution. The miscibility break interval is about 15% by weight (Figure 17-a). This break is considerably greater for the analyzed primary pyroxenes from Dawros rocks (Figure 17-b). Judging from the amount of residual solution,

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[6] A simplification is possible because pure terminal members have been used. This embraces intermediate members of the solid solution series, with a possible series of tetrahedrons constructed for earlier stages of the basalt crystallization. The position of the olivine-pyroxene boundary surface in such tetrahedrons reveals certain interesting modifications, because the olivine-pyroxene reaction ratio gives place to the cotectic one.

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[7] The various factors possibly leading to such an effect are not considered here.

FIGURE 17-a. MgSiO₃ – CaMgSi₂O₆ system.
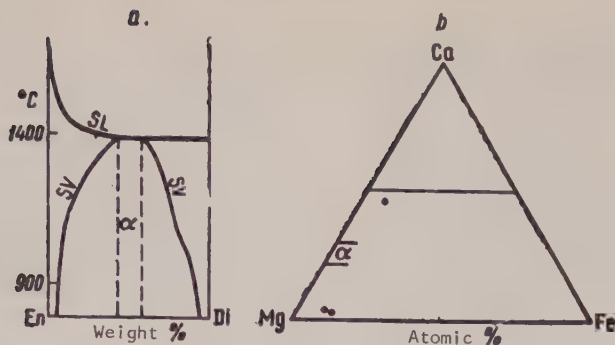
FIGURE 17-a. $MgSiO_3$ – $CaMgSi_2O_6$ system.

Curves plotted for solidus (SL) and solvus (SV); also
the miscibility break (α).

FIGURE 17-b. Composition diagram for pyroxene and
for the analyzed bronzite and primary diopside, with
the miscibility break as established for the enstatite-
diopside system.

now preserved in the lamellas of supplementary pyroxene (i. e. , enstatite and pyroxene), the analyzed minerals are typical primary pyroxenes of the intrusion.

The simplest assumption, for the present, would be that a greater miscibility break in natural magmatic systems, rich in water, is a result of depressed liquidus and solvus curves. Such a depression has been experimentally established for the $NaAlSi_3O_8 - KAlSi_3O_8 - H_2O$ system. Here, a depression of over $200°$ was obtained in raising the water pressure from a dry system of 2000 kgm/cm² (N. Bowen and O. F. Tuttle).

The participation of water has led to a drop in the liquidus temperature to the point where the diopside and spinel fields come together, which might prevent the appearance of plagioclase. However, such an effect is inadequate to eliminate all traces of plagioclase. Data on the chromespinel horizon indicate a crystallization and rock accumulation at the base of a still liquid magma. If the temperature interval between the crystallization of olivine and pyroxene, on the one hand, and of plagioclase on the other, is sufficiently large, it is possible that the general crystallization in Dawros occurred before the temperature necessary for plagioclase precipitation had been reached. That could have led to a physical exchange between the captured interstitial fluid in a slowly cooling crystallizing precipitate, and the still liquid magma immediately above it.

I quote here an appropriate passage from G. Brown's work: "If the interstitial fluid had completely recrystallized between primary crystals, the resulting rocks should carry minerals with a crystallization temperature below the primary precipitate temperature, or new minerals (e. g. , apatite and quartz in the Skaergaard gabbro) and marginal fringes on normally zoned primary minerals. It is believed that the absence of these rocks in the upper interval of the layered series (Ram) is the result of a diffusion process similar to that described by H. Hess (1939). With only a short interval separating the interstitial fluid from the overlying magma, crystallization of even a small amount of material out of the fluid will set up a composition gradient in the intermediate fluid and initiate a process similar to that described by N. Bowen, in 1921. It is then that a homogenous growth of the primary crystals could take place. On the other hand, a more rapid deposition of primary crystals would considerably increase the distance between the interstitial fluid in lower layers and the overlying liquid; as a result, the composition of the first one would not change much because of a diffusion of material from the overlying liquid" ([6], page 14).

An increase in the crystallization interval for pyroxene and plagioclase in a crystallizing melt was observed in a recent experimental work on the tholeiite-water system (H. Yoder, C. Tilley, [26, 27]). It is therefore probable that mother magma of the Dawros rocks was a water-rich, SiO_2 saturated basalt magma. Most probably it belonged to the basalt-andesite series whose derivatives are common in orogenic provinces (E. Osborn, [15]).

I have already used a number of quotations pertinent to the problem under study. I conclude with another one:

"We may suppose that a normal lime-alkali series of igneous rocks originates in fractional

crystallization of a tholeiite-olivine basalt magma which is intruded into the orogenic belts and is differentiated in a way assumed for the Cascade liquids.[8] The same primary magma but intruding nonorogenic provinces is differentiated in a way illustrated in the Skaergaard complex. The first way leads to an increase in silica with a consistent decrease in ferric iron; the second to an increase in the latter accompanied by a slight change, or even by a decrease, in silica, up to the last stages of crystallization. The first way generates liquids which solidify as such common rocks as andesite, dacite, rhyolite, granodiorite, and granite; the second tends to form a peculiar gabbro with a small amount of the terminal felsitic residue. The cumulative crystalline fraction, complementary to the lime-alkali liquid fraction, is presumably represented by common peridotite, serpentine, and other ultramafic rocks of orogenic belts" ([15], page 645).

Translated from the English
by O. A. Vorob'yeva

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SIGNIFICANCE OF THE ARGON-POTASSIUM RATIO IN OCEANIC OOZES[1]

by

A. Ya. Krylov, A. P. Lisitsin, and Yu. I. Silin

It has been established [6] that the Ar/K ratio in sand and clay originating in the disintegration of granitoids remains the same as in the original rocks. Two stages have been observed in the weathering of granite, from the change in the Ar/K ratio. At the first stage of fracturing and of breaking up of rocks into clastic material, the Ar/K ratio is somewhat reduced compared with fresh, unweathered granite. In the final products of weathering, sands and clastic clays, this ratio is restored to its original value, because of a natural selection of small feldspar "fragments" with "excess" potassium removed from their faces.

This thesis, of fundamental value for the Ar-K method, was checked on granite pebbles, sands, and sandstones of various ages, also on certain clays and sedimentary rocks of northern Tien Shan. New and important data corroborating the applicability of the Ar/K ratio in the dating of sedimentary rocks, from pebbles to fine clays, were obtained in this way. In all instances, the age determined from the Ar^{40}/K^{40} ratio turned out to be that of the source material; i. e., Caledonian granitoids and metamorphics [3, 5, 6].

The feasibility of dating K-feldspar from recent sediments (for paleogeographic study) was first demonstrated in the study of glacial sands of the Baltic region and of the Black Sea littoral sands [4].

An interesting check on the absolute age of terrigenous minerals in clastic sedimentary rocks can be made through a study of marine bottom sediments from various oceans. It is known that each sea and ocean has a source of sediments of its own, made up of rocks of diverse geologic age. In sampling the Bering Sea sediments, one can be certain that their K-feldspar and mica are not older than the Mesozoic, while those off eastern Antarctica

are apt to be Precambrian, and those off western Antarctica, Paleozoic or Mesozoic, etc. Clastic sediments off the oceanic islands far removed from the continents are of great interest in this connection. It goes without saying that recent marine sediments, particularly the deep sea oozes, differ in many ways from common "clastic" clays; i. e., those consisting of the finest mineral fragments. If it can be shown that the Ar^{40}/K^{40} ratio in recent oozes is the same as in their source material; i. e., in continental bedrock, the argon method will become quite promising in marine geology.

About 50 samples of bottom sediments from various parts of the world, collected by geologic groups of the Antarctic Marine Expedition [2, 7] and the SS Vityaz were used in this work. These samples were obtained from diverse climatic zones, from Antarctica to the equator, at depths ranging from a few tens of meters to 5500 m, and occurring under different geologic, hydrochemical, and hydrologic conditions. Virtually all types of bottom sediments were used, which made it possible to determine the stability of the Ar^{40}/K^{40} ratio under different geochemical conditions.

Before turning to the data so obtained, it is expedient to discuss certain aspects of the argon method as applied to clays.

I. PRESERVATION OF RADIOGENIC ARGON IN CLAYS AND OOZES

A complete, or at least considerable preservation of radiogenic argon in the finest subcolloidal particles of clay and ooze naturally raises a number of questions.

1. If the K-bearing fraction of clay and ooze is considered a mechanical sediment, the complete preservation of argon, an inert gas, in such a fine fraction may appear odd indeed. Certain experiments even seem to justify such doubts. Our own experience (Table 1) shows that the reverse is true. As shown in the table, the Ar/K ratio in various fractions of feldspar, ancient clays, and recent deep oceanic red clay, is virtually independent of grain size.

Table 1

Various fractions of feldspar in clays and oozes

Nos.	Rock	Fraction, mm	K, %	$\frac{Ar^{40}}{g} cm^3 \cdot 10^{-6}$	T, million years
1	Feldspar from north Karelian pegmatites	2—0.2	11.07	91.5	1450
		0.2—0.1	11.06	95.3	1490
		0.1—0.05	10.90	94.4	1500
		0.05—0.01	11.08	96.4	1510
		0.01—0.001	11.08	93.1	1465
		< 0.001	10.80	84.0	1380
2	Jurassic shale from Central Tien Shan	Monolith	2.97	4.26	345
		> 0.002	2.70	4.03	360
		< 0.002	3.05	4.52	355
3	Paleogene claystone from the Maikop formation of south Yergeni	Monolith	2.25	1.61	175
		> 0.005	2.00	1.48	180
		0.005—0.001	2.43	1.64	170
		0.001—0.0005	2.40	1.53	160
		< 0.0005	2.04	1.42	175
4	Paleogene silty claystone, Altai stage, Ferghana	Monolith	3.36	1.85	140
		0.1—0.3	3.33	1.86	141
		0.1—0.05	3.41	1.82	137
		0.05	3.42	1.86	138
5	Deepwater red clay from the Pacific Station 3156	Monolith	2.36	1.52	160
		0.05	1.98	1.20	155
		0.05—0.01	2.28	1.60	175
		< 0.01	2.48	1.47	150

2. A number of objections connected with the origin of clay minerals arise also in determining the age of K-bearing minerals in clay and ooze.

If the original Ar^{40}/K^{40} ratio in K-bearing clays is modified during their formation, their age as determined will not be that of their source rocks. However, it should be kept in mind that the pelitic fraction of oozes contains, besides the typical clay minerals, a permanent and important component of the finest fragments of stable primary minerals, including K-feldspar. Judging from the figures of Table 1, radiogenic argon is probably preserved, in many oozes, in those microcrystals of K-feldspar which contain the bulk of the potassium. A direct study of clay samples from various parts of the world, carried out by Z. N. Gorbunova, shows that fraction < 0.001 mm contains, besides the typical clay minerals, a large amount of clastic minerals and organic remains. As shown by an electron-microscopic study, the amount of these mineral fragments is especially large in iceberg and diatomaceous sediments, i. e., those whose sources have been affected mostly by mechanical disintegration, as is true for Antarctica.

3. It is also known that ion-exchange reactions, including those affecting to some extent the K-content, may take place in clays and recent oozes. We have performed a number of experiments on oozes and clays of various age and composition, to determine the amount of potassium adsorbed by the oozes. The results are given in Table 2 which shows that potassium adsorbed from water has no appreciable effect on clays and oozes. Thus, the field data suggest that the bulk of potassium in clays and oozes is present in the finest rock and mineral fragments rather than in an ion-exchange state.

4. Serious difficulties may arise when the bottom sediments contain authigenic K-bearing minerals. Glauconite is the most common mineral of the type. This mineral is readily identified under the microscope. If its content is appreciable, it should be removed from the sample, or the data obtained will be greatly distorted. When the removal of glauconite is impossible, the age of the terrigenous minerals cannot be determined by the argon method, as we shall presently see. Besides the authigenic mineral, small amounts of potassium may be present also in organic remains which are a common component of oozes. As of now, the K-content is unknown for most sediment-making organisms (more precisely, for their skeletal remains), and additional study is needed. Our experience has shown that organic oozes, specifically the diatomaceous and foraminiferal oozes, are a poor subject for argon dating; they yield many extraneous gases; consequently, the accuracy of the argon determination is reduced.

Table 2

Potassium content in clays and oozes after processing with H_2O,
10% HCl, and 0.5N NH_4Cl

Nos.	Rock or mineral	Sampling locality	In original sample	K-content, %		
				After processing		
				H_2O	HCl	NH_4Cl
1	Microcline	Northern Karelia	11.0	11.0	10.9	10.8
2	Clay J	Tien Shan	3.0	2.9	2.8	3.0
3	" Pg	Ferghana	3.3	3.3	3.3	—
4	" Pg	Northern Caucasus	2.0	2.0	2.1	2.0
5	Kaolin	Chasov"yarsk deposit	0.86	0.87	0.91	0.8
6	Iceberg ooze	Davies Sea	3.1	3.0	3.1	3.1
7	Diatomaceous ooze	Indian Ocean	2.7	2.7	2.7	2.7
8	Dead deepwater clay	Pacific	2.3	2.2	2.1	2.2

It can be stated, in summarizing, that with
the content of glauconite and organic remains
accounted for, recent oozes may be suitable
for dating their terrigenous source material.

II. THE ARGON-POTASSIUM RATIO AND
ABSOLUTE AGE OF K-BEARING MINERALS
IN RECENT OCEANIC SEDIMENTS

The content of argon and potassium in terri-
genous minerals of oozes, along with their
absolute age, is shown in Table 3.

A general description of the sediments
studied is given in Tables 4, 5, 6, and 7. The
samples analyzed varied greatly in their granu-
lometric, chemical, and mineral compositions
and were obtained from various depths (59 to
5501 m) and at various distances from shores
(20 to 1700 km). These sediments, from
pebbles and gravel to fine clay oozes at some
stations (such as station 460) were analyzed in
two fractions: sandy ooze and gravel. The age
values so obtained turned out to be quite sim-
ilar, which is an additional corroboration of
our thesis.

Used in the analysis were samples with a
variety of physical compositions: clastic (ice-
berg, terrigenous), biogenic (diatomaceous and
foraminiferal), volcanic (lavas, ash), and
polygenetic (red deepwater clay), coming from
different geographic zones: iceberg oozes of
the Indian and Pacific sectors of Antarctica;
diatomaceous and foraminiferal sediments of
the Indian Ocean; deepwater red clays of the
Indian and Pacific Oceans; and terrigenous
sediments of many seas and oceans (Figure 1).

The content of pelitic material (fraction
< 0.01 mm) was 84 to 88%, in some samples,

with up to 60% of fraction < 0.001 mm. In mos
samples, the insoluble residue; i.e., largely
clastic and clay minerals, was 80 to 95% of the
total; only in diatomaceous and foraminiferal
sediments was the insoluble residue less than
50%, a fact reflected in the higher error of the
absolute-age determination.

With regard to the mineral composition of
these sediments, the fraction studied was the
most representative, 0.1 to 0.05 mm (coarse
silt). Both the heavy (d > 2.70) and the light
subfractions were analyzed by the immersion
method. In addition, the heavy fraction (0.25
to 0.1 mm) of a comparatively small number o
samples was studied with the binocular micro
scope and by concentrate analysis.

For convenience, the mineral analyses are
listed in order of their station numbers, with
out reference to the types of sediments (for th
type classification, see Table 3). Tables 5 an
6 show that K-minerals (orthoclase, micro-
cline, muscovite, biotite, chlorite) are prese
usually in fairly large amounts; for example,
the amount of orthoclase and microcline in a
number of samples reaches 25 to 29%; chlorit
and biotite, up to 20%, with a considerably
smaller amount of muscovite. It is of impor
tance that recent glauconite with its K-conten
is largely missing in the samples or accounts
for less than 2% of the total. Only in two
(stations 120 and 122) diatomaceous oozes fro
the vicinity of Kerguelen Island (South Indian
Ocean) was its content as high as 91%. From
what has been said before, the absolute age o
these sediments, as determined by the argon
method, should be close to zero, which indee
has been corroborated by direct measuremen
(Table 3).

These data reflect well the mineralogy of

Table 3

Absolute age of terrigenous material from various oozes

Nos.	Station No.	Depth, m	Distance fr. shore m	Sampling locality	K. %	Ar^{40}, $\frac{cm^3}{z} \cdot 10^{-6}$	Age million years
				I. Iceberg Deposits of Antarctica			
				1) The Indian Ocean Zone			
1	235	2869	56	Sector of Queen Maud Land	2.47	3.56	345+50
2	243	5193	1000	"	2.55	3.64	345+150
3	226	934	150	"	1.80	2.18	295+35
4	206	1656	85	Sector of Kemp Coast	2.22	3.56	380+110
5	193	187	75	" " Robertson Land	1.14	3.62	690+70
6	193	114	65	" " "	1.50	3.05	475+40
7	190	683	130	Christensen Coast sector	1.51	3.14	485+60
8	185	308	170	"	2.20	4.32	460+80
9	181	3469	445	"	2.65	5.64	490+40
10	158	582	56	Davis Sea	2.40	4.77	460+45
11	161	2654	170	"	2.44	7.19	650+85
12	111	2825	260	Davis Sea sector	3.25	5.40	390+30
13	14	428	140	Shackleton Glacier sector	1.66	3.40	475+30
14	15	206	240	"	1.20	3.91	710+50
15	18	456	260	"	1.89	4.98	590+50
16	23	639	130	Near Knox Coast	2.76	7.57	610+70
17	30	197	5	Near Sabrina Coast	2.30	7.12	670+70
18	35	3122	260	"	2.33	5.94	575+180
19	36	3764	350	"	2.33	7.03	660+160
20	330			"	3.48	10.27	650+30
21	331			"	2.84	8.98	690+70
22	41	223	120	Discovery Land area	1.24	5.95	960+80
23	43	418	110	Banzare Land sector	2.88	9.07	680+50
24	44	1016	65	"	3.03	11.0	730+75
				2) The Pacific Zone			
25	51	3016	220	Sector of George V Coast	2.77	4.02	350+50
26	54	2641	75	Balenny Island area	2.00	1.62	200+100
27	55	2733	30	"	1.48	0.15	25+25
28	57	2937	240	Otts Coast sector	2.12	4.67	505+80
29	373	1895		"	1.80	2.16	290+120
30	404	4413	780	Mary Byrd Land Sector	2.30	2.51	270+120
31	377	523		Scott Island	2.48	0.38	40+20
32	460	393	30	Drake Strait	1.95	1.49	190+20
33	460			Same place, different fraction	1.88	1.40	185+40
				II. Diatomaceous Sediments (Indian Ocean)			
34	107	4400	890	Shackleton Glacier sector	1.38	2.27	390+390
35	120	264	110	Heard Island	2.81	0	0
36	122	59	220	Kerguelen Island	2.52	0	0
				III. Foraminiferal Sediments (Indian Ocean)			
37	260	1808	185	South Africa	1.85	1.38	190+10
38	267	4400	780	"	1.59	1.68	250+15
39	318	4512	1100	Sumatra area	1.05	0.65	155+80
				IV. Red deepwater clay (Indian Ocean)			
40	307	5501	1700	South Cocos Islands	2.15	2.18	250+25
41	316	4853	1200	Latitude of Java	2.11	0.68	80+60
				V. Red deepwater clay (Pacific Ocean)			
42	3156	5520		Northwestern part of ocean	1.98	1.20	155+40
43	1819	5000		"	2.39	1.41	145+35

Nos.	Station No.	Depth, m	Distance fr. shore m	Sampling locality	K, %	$\frac{Ar^{40}, cm^3}{e} \cdot 10^{-5}$	Age million years
				V I. Terrigenous Oozes			
			1)	Off Indian coast (Bay of Bengal)			
44	327	2230	330	Bay of Bengal	2.70	2.79	255±15
45	329	36	20	Ganges' Mouth	2.36	1.32	140±20
			2)	Off East Africa			
46	147	5136	330	Somali	1.10	3.41	680±50
47	148	5130	100	"	0.55	1.34	560±150
			3)	Off New Zealand			
48	78	246	30	Tasman Sea	2.12	0.64	80±20
			4)	Bering Sea			
49	990	90	220	Bering Sea	1.85	0.4	50±40
50	972	114	430	"	1.52	0.2	20±20
51	2463	3782	240	"	1.68	0.6	90±60

those complexes where the fractions analyzed are predominant or at least substantially important; i. e. , sandy and silty sediments. Such data, however, are not representative of fine ooze whose mineralogy is determined only by a study of clays. Mineralogy of the fine pelitic fraction (< 0.001 mm) for all types of bottom sediments tabulated (except for those from the South Pacific) was studied by Z. N. Gorbunova, at the U. S. S. R. Academy of Sciences Institute of Oceanography. She has determined that the distribution of clay minerals in the Indian Ocean is zonal to a certain extent. Its extreme south, including the provinces of iceberg and diatomaceous sediments, is occupied by hydromicaceous clay minerals (hydrobiotite). In the central part, in the province of foraminiferal oozes and red deepwater clay, finely dispersed, hydromicaceous, beidellitized minerals have been observed. Finally, hydromicaceous beidellitized minerals with a considerable addition of kaolinite have been identified in the northern part of the Indian Ocean, including the Bay of Bengal, and at isolated stations (303, 310) in the central part of the ocean and in the Tasman Sea. As seen from X-ray photographs of oriented preparates and from electron-microscope photographs, the amount of kaolinite at stations 303, 307, and 329 is quite large, not inferior to that of hydromica and even exceeding it, in isolated instances.

These data on the composition and distribution of clay minerals show that the formation of the clay mineral complex, even in deep oceanic sediments, is affected by soil-making processes on land and by the subsequent transportation of fine particles to remote and deep reaches of the ocean. Insofar as soil-forming processes are subject to climatic zonation, the distribution of clay minerals in marine and oceanic sediments, too, is subject to the same zonation, in an attenuated form.

In evaluating the role of clay minerals in fine oozes, as carriers of potassium, it should be kept in mind that most of them contain relatively little potassium if any at all.

Upon our request, V. V. Kurbatov (Radium Institute of the U. S. S. R. Academy of Sciences) did an X-ray study of a number of fine fractions of clay and ooze. It turned out that these fractions generally contained up to 5 or 10% microcline, and often as much as 10% biotite.

It is probable that these terrigenous minerals are the principal carriers of potassium in oozes. If that is true, we are quite justified in assuming the absolute age of oozes to be that of their original clastic components.

SUMMARY

1. Radiogenic argon is preserved fully or nearly so, in finest (up to < 0.001 mm) particles of feldspars and micas, the components of most clay and ooze.

2. No appreciable adsorption of potassium by oozes, from oceanic water, has been observed. The bulk of potassium in oozes is present in fragments of terrigenous minerals (K-feldspar and micas) or in glauconites and in the products of submarine volcanism.

3. These premises, along with our earlier studies of the preservation of radiogenic argon in the products of disintegration of bedrock [3, 4, 6], lead to the conclusion that most oceanic oozes can be used in determining the absolute-age (by the K-Ar method) of their
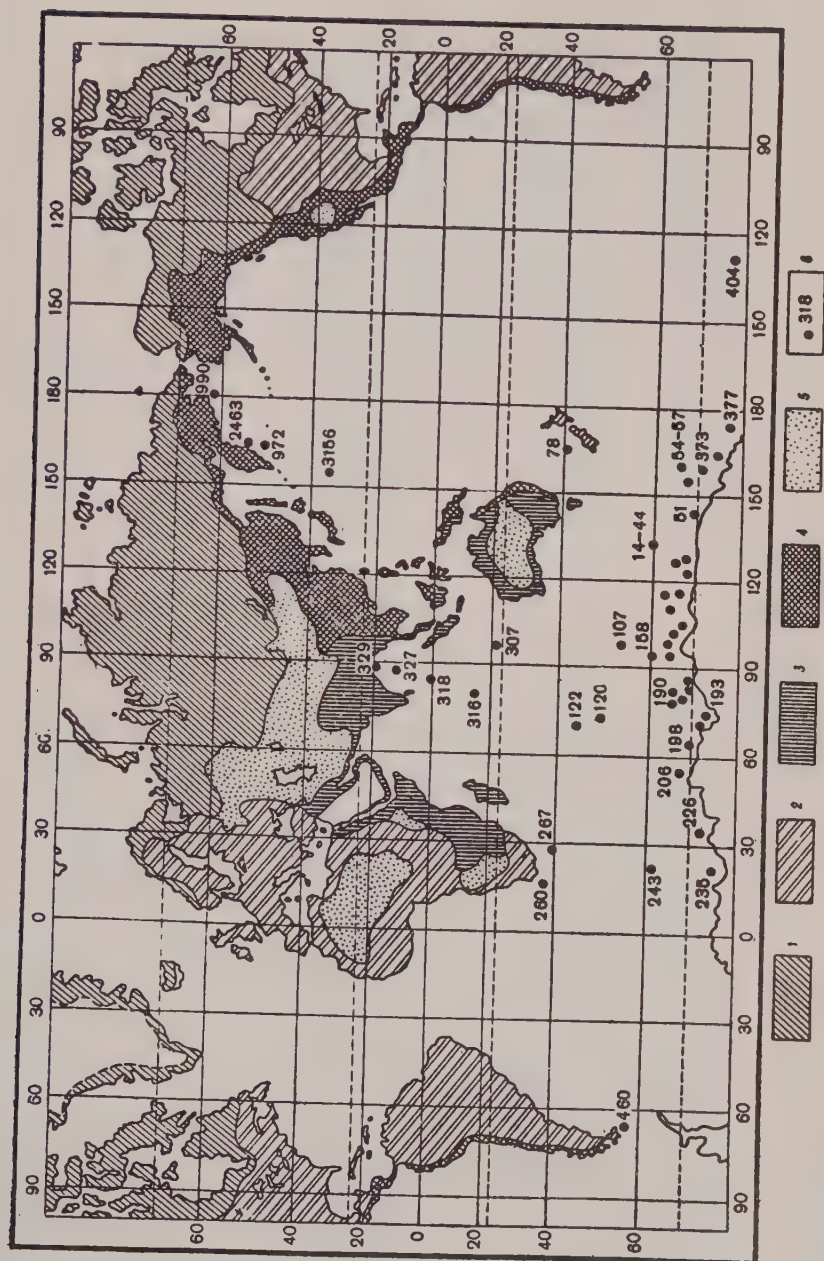
FIGURE 1.   Ocean provinces and sampling localities

1 - Arctic Ocean; 2 - Atlantic; 3 - Indian; 4 - Pacific; 5 - Issueless provinces; 6 - Station numbers.

Table 4

General characteristic and the granulometric composition of the oozes analyzed

Granulometric composition (fraction in mm)

Station No.	Lat.	Long.	Sediments	>1	1—0.5	0.5—0.25	0.25—0.1	0.1—0.05	0.06—0.01	0.01—0.005	0.005—0.001	<0.001
			1. Iceberg Sediments of Antarctica (Indian Ocean)									
14	65°26.2'	94°55.0'	Sand, green-gray, with pebbles and rubble	5.03	13.11	13.66	18.09	24.89	7.56	17.57*	—	—
15	64°35.6'	96°51.7'	Siltstone, yellow-gray, with pebbles and rubble	0.27	1.02	4.50	19.23	57.24	9.29	8.46*	—	—
18	64°14.5'	99°12.0'	Ooze, silty sand, with pebbles and rubble	48.40	5.82	6.33	8.17	22.62	4.10	4.56*	—	—
23	65°14.0'	107°33.6'	Ooze, silty clay, light brown, with pebbles	—	—	—	8.21*	8.20	26.13	10.12	28.41	18.93
30	65°52.1'	111°40.0'	Ooze, silty clay, green-gray, with gravel	—	—	—	5.63*	29.71	13.59	22.11	10.16	18.80
35	63°42.2'	117°21.1'	Ooze, clay, brown-gray	—	—	—	0.43*	3.62	7.87	42.85	10.34	34.89
36	62°54.9'	118°52.5'	Ooze, fine silt, green-gray	—	—	—	1.97*	1.64	42.06	3.02	8.09	42.62
41	65°42.0'	124°28.0'	Sand, green, with gravel	14.04	9.04	11.99	23.62	35.29	3.25	2.77	—	—
43	65°36.5'	125°23.2'	Ooze, sandy silt, with gravel and rubble	14.27	5.32	5.83	8.40	19.46	15.34	3.72	5.71	21.32
44	66°07.7'	128°24.9'	Ooze, silty clay, green-gray	—	—	—	3.51*	4.63	25.56	6.43	26.26	33.56
111	64°24.6'	92°52.3'	Ooze, silty clay, brown-gray, with gravel	—	—	—	4.31*	5.49	14.90	38.85	6.27	30.17
158	66°16.4'	90°50.4'	Ooze, silty clay, with very coarse sand	2.24	10.42	12.60	18.72	30.46	6.54	0.37	11.2	17.51
161	65°24.8'	89°35.2'	Ooze, silty clay, light-brown, with very coarse sand	—	—	—	1.59*	4.57	39.52	19.66	10.98	23.88
181	64°59.5'	77°09.9'	Ooze, sandy clay, with occasional rubble fragments	1.71	—	—	1.92*	2.52	22.78	22.94	6.10	43.74
185	67°05.7'	77°02.5'	Ooze, silty, green-brown, with rubble	—	13.57	10.78	17.83	29.33	14.57	12.21**	—	—
190	68°42.7'	74°02.2'	Ooze, silty clay, green	0.48	0.35	0.31	0.38*	1.89	35.23	62.50**	—	—
193	67°24.8'	70°33.0'	Ooze, silty, green-gray	—	—	—	37.73	53.01	2.69	3.83**	—	—
198	66°48.2'	63°50.0'	Ooze, sandy, green-gray, with very coarse sand	29.49	5.66	16.81	24.10	19.15	1.19	3.24**	—	—
206	65°40.2'	56°57.2'	Ooze, silty clay, brown, with rubble	2.44	1.43	5.45	8.53*	11.40	35.39	14.12	4.39	26.16
226	67°28.8'	32°38.5'	Ooze, silty, with small gravel and foraminifera	—	—	—	6.71	35.91	22.29	7.79	2.87	14.98
235	69°46.3'	20°19.6'	Ooze, silty clay, green-gray, with small addition of very coarse sand, foraminifers, and sponges	—	—	—	2.56*	9.80	26.83	21.49	2.94	36.38
243	61°33.8'	20°00.5'	Ooze, clayey, gray, with remains of diatomaceous algae	—	—	—	2.33*	1.36	28.34	24.46	9.72	33.78
			The Pacific									
51	65°01.2'	144°36.0'	Coarse silt, brown-gray, with gravel	—	—	—	1.20*	35.58	29.28	23.46	0.55	9.92
54	66°57.0'	161°25.2'	Ooze, silty clay, light-brown, with gravel and rubble	—	—	—	7.87*	5.25	32.28	22.08	19.77	12.74
55	65°42.1'	162°33.8'	Ooze, fine silt, brown-gray, with rubble	—	—	—	2.26	12.44	39.59	45.70**	—	—
57	64°03.0'	161°09.2'	Ooze, silty clay	—	—	—	—	—	—	—	—	—

No.	Lat.	Long.	Description										
373	69°31.5'	165°07.8'	Ooze, silty clay	—	—	—	—	—	—	—	—	—	—
377	67°23.5'	179°52.6'	Gravel and coarse sand, with addition of basic volcanic pebbles	—	—	—	—	—	—	—	—	—	—
404	67°16.2'	128°48.0'	Diatomaceous ooze, brown–gray	—	—	—	—	—	—	—	—	—	—
460	61°15.4'	56°22.8'	Gravel with sand and pebbles	—	—	—	—	—	—	—	—	—	—

II. Diatomaceous Sediments (Indian Ocean)

No.	Lat.	Long.	Description										
107	57°47.0'	99°22.5'	Ooze, light-brown, diatomaceous	6.94	—	—	—	1.02*	2.72	16.33	11.89	15.61	52.42
120	52°15.5'	73°47.0'	Sand, green–black, with gravel	—	4.58	4.63	—	7.76	38.25	18.91	18.16	13.90	2.0
122	49°32.4'	70°22.5'	"	3.19	0.08	0.24	—	3.59	73.78	6.11	12.65**	—	—

III. Foraminiferal Sediments (Indian Ocean)

No.	Lat.	Long.	Description										
260	36°18.9'	19°36.9'	Silt with foraminifera and glauconite	—	—	—	—	24.10*	21.20	14.70	40.0**	—	26.62
267	40°37.8'	29°13.5'	Ooze, silty clay, brown–gray, with foraminifera and occasional FeMn concretions	—	—	—	—	13.06*	13.75	21.04	18.56	6.96	—
318	00°01.8'	88°21.8'	Clay ooze, foraminiferal, siliceous, with silty material radiolaria, and volcanic glass	—	—	—	—	4.93*	4.11	16.46	24.90	11.79	37.80

IV. Red Deepwater Clay (Indian Ocean)

No.	Lat.	Long.	Description										
307	21°26.4'	97°05.4'	Very fine red deepwater clay free of concretions and inclusions	—	—	—	—	0.29*	5.57	24.23	52.05	5.94	11.92
316	04°50.6'	88°15.9'	Fine buff-red deepwater clay enriched in volcanic glass and ash, radiolaria, diatoms, and sponge spicules.	—	—	—	—	0.76*	2.28	32.70	23.47	9.05	31.74

The Pacific

V. Terrigenous Oozes

No.	Lat.	Long.	Description										
3156	39°57.3'	164°52.4'	Clay ooze	—	—	—	—	1.0*	2.0	14.0	83.0**	—	—
1819	58°42.8'	150°28.8'	Silty clay ooze	—	—	—	—	0.2*	22.2	22.7	13.5	12.6	28.8

1) Off Indian coast (Bay of Bengal)

No.	Lat.	Long.	Description										
327	19°04.0'	88°06.6'	Clay ooze, dark–brown, calcareous	—	—	—	—	0.27*	0.54	22.93	30.18	19.94	26.1
329	20°55.2'	88°01.5'	Silt, gray–brown, calcareous	—	—	—	—	0.65*	42.44	13.82	43.09**	—	—

Table 4 (continued)

Station No.	Lat.	Long.	Sediments	\<1	1–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.01	0.01–0.005	0.005–0.001	\<0.001
			2) Off East African Coast									
147	05°19.2'	53°00.0'	Clay ooze, brown	—	—	—	0.63*	3.81	11.1	18.38	5.91	60.17
148	07°07.0'	52°42.0'	" "	—	—	—	0.2	7.76	28.30	63.74**		
			3) Off New Zealand (Tasman Sea)									
78	40°01.0'	172°19.0'	Clay ooze, blue-gray, slightly calcareous	—	—	—	26.0*	5.76	18.98	11.18	54.21	7.29
			4) Bering Sea									
972	56°56.2'	173°59.0'	Clay ooze	—	—	—	0.3*	1.1	28.6	32.9	3.6	13.6
990	62°37.3'	175°51.9'	Ooze, finely silty	—	—	—	0.3*	10.9	46.1	26.78	5.08	10.7
2463	57°21.5'	167°52.5'	Clay ooze	—	—	—	0.2	0.4	12.5	86.9**	—	—

* Sum of fractions > 0.1 mm.
** Sum of fractions < 0.01 mm.

source rocks, thereby contributing to the solution of many problems in marine geology and paleogeography.

4. More specifically, we submit the following observations.

. The age of the terrigenous fraction of oozes off eastern Antarctica is approximately the same as for the typical coastal rocks [8]. The oozes are much younger off western Antarctica (Pacific sector), where the land is made up of younger rocks. A complete age correspondence here is not to be anticipated, because icebergs carry terrigenous material over a considerable distance, bringing about a certain obliteration of differences in the composition of the oozes. In this connection, it becomes possible to determine the "average" of prevailing age of Antarctic rocks. The fact is that all of Antarctica is covered by a thick ice cap, so that its geology can be inferred only from small outcrops along the coast. The glaciers, in their secular movement toward the ocean, pick up an "average sample" of the continent and deposit it offshore. The mixing of such a "sample" is done by drifting icebergs. In a more careful dating of oozes, this phenomenon can be taken advantage of, in studying the main direction of drift icebergs, past and present (from deeper segments of the bottom cores).

From material now on hand, it can be inferred approximately that the "average age" of eastern Antarctic rocks is about 500 to 700 million years, with about 200-300 million years for western Antarctica. Deepwater Pacific clays (their terrigenous fraction) are younger, being about 150 million years old, which is natural considering that the Pacific is surrounded by young tectonic and igneous provinces. A direct corroboration of this explanation is found in Bering Sea oozes. Their age has been determined quite approximately (low Ar^{40} content) but it is unquestionably young (largely Tertiary). This, again, is natural in view of the fact that the Bering Sea coast represents a young igneous province.

The northern part of the Indian Ocean has yielded different values for the age of its oozes. Samples from stations 147 and 148, taken off the east coast of Africa, suggest a comparatively ancient age, quite understandably because of the wide distribution of Precambrian rocks over the African continent [1, 9]. The terrigenous component of red oozes off Cocos Islands (stations 307 and 316) is about as old as the Pacific red oozes (stations 3156 and 1819) which is understandable in view of the community of the source of sediments.

Terrigenous minerals in the Bengal Bay oozes are younger than those in oozes of the Antarctic and African sectors of the Indian Ocean probably because the Ganges carries i

Table 5

Mineral composition of the light fraction of certain oozes*

Station No.	Quartz	Orthoclase	Microcline	Plagioclase	Glauconite	Organic remains	Volcanic glass and ash	Other minerals
15	82.9	7.5	2.8	1.5	—	1.5	—	3.8
18	67.7	9.2	—	10.6	0.5	—	—	12.0
30	70.7	15.5	1.3	4.4	—	8.1	—	10.0
35	45.5	28.5	0.6	3.0	0.2	22.2	—	25.2
36	1.0	0.4	0.1	0.5	0.3	11.4	—	86.3**
41	85.9	6.0	0.6	1.6	—	2.8	—	2.1
43	63.7	26.9	1.6	4.9	2.9	—	—	0.0
44	47.5	15.6	1.4	2.4	—	33.1	—	0.0
51	67.5	21.2	0.7	1.4	0.7	6.1	—	2.4
54	15.2	0.6	—	1.1	—	4.4	14.9	63.8
55	8.2	—	—	2.4	0.2?	0.9	53.5	35.0
78	4.7	1.0	—	0.7	—	93.0	—	0.5
107	2.5	0.4	—	0.1	—	97.0	—	0.0
111	59.2	9.0	0.9	3.3	—	26.4	—	1.2
120	6.9	—	—	0.6	81.8	2.2	1.8	6.7
122	63.1	—	—	5.7	17.6	—	12.6	2.0
158	64.7	21.2	—	4.2	—	6.9	—	3.0
161	69.6	24.1	1.4	2.8	—	0.7	—	1.5
181	65.6	—	0.9	2.6	3.6	27.3	—	0.0
185	63.6	24.8	0.3	7.2	—	2.4	—	1.7
190	71.6	7.2	—	6.9	—	8.3	—	6.0
226	45.5	1.4	0.2	2.6	3.2	46.6	—	0.5

*Analyses performed at the Geochemical Laboratory of the Arctic Institute, under the direction of Z.A. Glagoleva.
**Including 85% dolomite

oad from comparatively younger tectonic pro-
inces.

The Recent age of the terrigenous fraction in
oozes off the islands of Heard and Kerguelen
stations 120 and 122) is determined by the pre-
ence of considerable recent volcanic material
nd of glauconite. All these explanations are
merely preliminary and general. Each individ-
ial analysis or group of analyses calls for a
pecific explanation, depending on the physical
omposition of the ooze and of the local condi-
ions of its deposition.

The obscure points transpiring in the study
f individual age values usually are readily
larified through an analysis of all the data
abulated; they provide a comprehensive de-
cription of most samples. For lack of space,
ve cannot go into a detailed analysis of them.

5. Many types of oozes (especially those
ontaining more sand and gravel) in seas and
ceans are a suitable subject for dating source
material, by the argon method. The oozes with
much organic matter, glauconite, and the pro-
ucts of recent volcanism, are less suitable for
hat purpose. Such additions must be eliminated

prior to the analysis, lest the age values for
terrigenous source material be grossly dis-
torted (depressed, as a rule, or quite tentative).

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Table 6

Mineral composition of the heavy fraction of certain oozes

Station No.	Muscovite	Biotite	Chlorite	Glauconite	Iron ore, black	Opaque non-ore	Leucoxene	Limonite	Garnet	Zircon	Epidote	Zoisite, clinozoisite	Olivine	Sphene	Rutile	Tourmaline	Amphibole	Rhombic pyroxenes	Monoclinic pyroxenes	Sillimanite	Apatite	Barite celestite	Volcanic glass and ash	Others
15	—	—	2.1	—	28.9	1.8	1.4	1.8	48.9	2.5	2.9	2.4	0.2	—	0.4	0.4	4.0	0.7	0.7	1.2	1.0	0.2	—	0.9
18	—	2.3	10.4	—	31.1	8.0	0.5	4.5	16.9	4.4	1.1	1.9	—	0.2	—	—	11.4	2.6	—	—	3.4	0.5	—	0.4
30	—	2.2	0.7	—	18.4	2.9	0.3	9.1	12.9	7.4	0.7	0.6	—	—	0.9	2.3	40.1	0.1	—	0.6	1.0	—	—	0.0
35	2.3	1.6	1.6	—	15.1	2.2	0.3	18.9	10.3	4.5	0.6	2.6	—	3.2	3.9	—	41.9	—	—	—	0.9	2.0	—	0.0
36	—	2.0	3.2	—	12.8	2.4	0.1	2.9	2.2	6.3	—	5.4	—	0.6	0.2	0.4	14.4	—	0.4	—	2.8	—	—	36.5*
41	—	—	0.8	—	17.2	5.8	3.5	1.0	8.8	6.1	8.2	0.5	—	1.6	—	0.4	37.8	0.4	0.9	1.1	0.6	—	—	2.8
43	—	4.5	6.7	0.1	12.0	4.9	0.5	2.8	4.9	6.2	4.9	1.7	—	0.1	—	0.3	46.1	—	—	—	2.0	—	—	0.0
44	—	4.6	1.1	0.1	12.5	4.1	0.5	4.2	1.7	5.6	2.0	1.6	—	—	1.4	0.5	59.48	—	—	0.2	1.5	—	—	0.0
51	—	20.4	1.8	—	16.9	4.2	1.9	5.0	5.4	9.4	3.4	—	12.2	0.5	—	1.4	17.0	3.8	0.2	—	3.0	—	—	3.2
54	—	—	—	—	4.2	—	—	16.0	—	—	—	—	21.0	—	—	—	—	0.5	0.8	—	—	—	65.0	1.4
55	—	0.4	0.3	—	1.0	—	—	3.6	1.—	—	—	—	4	—	—	—	0.3	—	12.6	—	—	—	72.8	0.0
78	—	—	—	—	4.3	73.1	—	2.2	2.3	1.9	—	1.3	—	0.4	—	—	1.9	1.0	—	—	2.7	—	—	0.7
107	—	5.4	6.8	—	35.2	—	0.8	33.8	1.3	—	1.3	0.4	—	—	—	—	9.5	2.7	1.3	—	0.8	—	—	0.0
111	2.1	7.6	5.1	—	17.4	4.5	—	14.9	9.0	1.5	1.7	—	—	—	—	—	31.5	0.4	29.8	—	—	—	3.5	0.6
120	—	—	—	0.1	49.3	2.2	—	12.3	—	—	—	—	—	—	—	—	2.4	—	15.6	—	—	—	—	0.4
122	—	0.1	0.8	1.3	41.2	8.4	—	29.6	—	—	—	—	—	—	—	—	3.0	—	—	—	—	—	—	0.0
158	—	1.0	2.5	—	3.8	1.0	0.4	0.2	4.0	1.0	—	1.5	—	0.6	—	—	78.6	0.4	1.3	0.4	3.6	—	—	1.0
161	—	19.3	2.6	1.9	8.3	2.8	0.2	0.5	6.3	1.1	0.9	1.7	—	0.7	—	—	50.4	0.4	1.6	—	2.4	—	—	1.1
181	—	6.8	0.4	—	6.9	3.5	—	7.2	5.4	5.9	1.0	2.6	—	0.2	0.5	1.4	49.9	2.7	—	—	2.9	—	—	1.9
185	—	0.5	—	—	22.2	1.0	0.2	0.2	41.7	0.5	—	2.4	0.5	0.2	0.2	1.0	23.6	1.6	—	1.7	1.2	—	—	0.2
226	—	4.7	1.3	0.1	9.0	1.3	—	1.8	14.7	3.9	1.8	2.4	—	0.1	1.1	—	49.0	—	3.2	—	3.9	—	—	0.1

Brookite is absent in all concentrates; staurolite has been observed only at stations 41 and 158; disthene, only at station 15; andalusite, at stations 41 and 226; topaz at stations 36 and 41; hematite, at station 54.
*Dolomite.

Table 7

Chemical composition of certain oozes

Station No.	Insoluble residue	Sum of organic components	Including			
			SiO_2 amorph.	$CaCO_3$	$C_{org.}$	P
			Iceberg Deposits of Antarctica			
			1) Indian Ocean			
23	86.412	13.588	13.18	—	0.36	0.048
30	82.863	17.137	4.62	12.42	0.04	0.057
35	78.242	21.758	20.10	1.23	0.38	0.048
36	82.285	17.715	17.00	0.18	0.53	0.005
44	84.523	15.477	14.81	0.23	0.43	0.007
111	89.475	10.525	5.74	4.50	0.28	0.005
158	89.755	10.245	9.55	0.25	0.38	0.065
161	89.919	10.081	9.33	0.23	0.24	0.061
190	55.778	44.222	43.15		1.07	0.02
193	96.649	3.351	3.20		0.12	0.031
243	75.667	24.333	23.60	0.32	0.37	0.043
			2) Pacific			
54	90.87	9.13	8.16	0.59	0.42	0.14
57	80.95	19.05	3.89	14.24	0.92	—
			Diatomaceous Sediments (Indian Ocean)			
107	38.80	61.20	60.9	0.07	0.23	
120	83.68	16.32	13.90	2.00	0.42	
			Foraminiferal Sediments			
			1) Indian Ocean			
260	40.926	59.174		57.88	1.22	0.074
267	40.529	59.471		59.02	0.37	0.081
			2) Off East African Coast			
147	83.734	16.266	8.97	6.53	0.76	0.006
148	60.264	39.736	7.27	31.84	0.62	0.006
			3) Tasman Sea (off New Zealand)			
78	75.213	24.787	0.73	23.45	0.6	0.007

*Analyses performed at the Geochemical Laboratory of the Arctic Institute, under the Direction of O.I. Zelenskaya.

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GEOLOGIC CONDITIONS OF FORMATION OF BOTTOM SEDIMENTS IN KARABOGAZ-GOL IN CONNECTION WITH FLUCTUATIONS OF THE CASPIAN SEA LEVEL[1]

by

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The Karabogaz-Gol (Figure 1), located on the east Caspian coast, is known in world literature as the classic example of a marine lagoon where huge masses of salt deposits and other highly concentrated saline deposits have been and still are accumulating.

The area of the gulf is about 18,000 km^2. Deeply incised into the land, it is separated from the sea by northern and southern sand spits extended meridionally. They are separated by Karabogaz Strait which connects the gulf and the sea.

Not a single river flows to the Karabogaz-Gol. Extending to the north and east of it is the Ust-Urt desert plateau; the sandy desert of Kara Kum touches it in the southeast. Its coast is an arid desert.

Overlain by the sands at the base of the spits are dense Ancient Caspian limestones changing downward to calcareous shell-bearing sandstones, with a total thickness up to 10 m. They are underlain by dense gypsiferous Oligocene claystone. The two horizons dip west; in many shallow places they form numerous reefs and submarine ledges.

The surface of these spits is hilly to barchan-like. Present among the barchans, in the axial parts of the spits are saline troughs, dry and issueless, but still preserving evidence of a recent connection between the sea and the bay.

Exposed in isolated places of both the northern and southern spits are ledges of ancient Caspian limestones and sandstones, the former submarine reefs. Well expressed is the ancient beach zone and a single terrace standing to 5 m above the present sea level, a testimony to the last Caspian transgression.

Karabogaz-Gol is fed by Caspian waters, through the strait, and its hydrologic and hydrochemical regimen is closely related to the sea-level regimen. Waters of the Caspian, because of the considerable difference in their level as compared with the bay, continuously flow to the gulf where they are evaporated because of the arid climate. Brine accumulates in the bay, and salts are deposited as the result of complex physicochemical processes.

Thus, Karabogaz-Gol can be compared to a vast evaporation vat where sea water gains in density. The volume of inflow, and consequently the water balance of the bay, are determined on the whole solely by the height of the Caspian level.

The amount of precipitation falling on the water area of the bay does not exceed 10% of the inflow.

The Caspian sea level is subject to wide fluctuations. It has fallen almost three meters in the last 25 to 30 years. Most students explain that by climatic causes [3, 5, 13, 16]. The recent warming up of the climate has caused a reduction in the Volga discharge, and consequently a drop in the Caspian Sea level; the latter, in turn, has caused a drop in the Karabogaz-Gol level.

Another reason for the Caspian level drop is human activity in connection with the building of water storage basins for the Volga and its tributaries [2].

Because of the drop in the Caspian Sea level, the flow of sea water into the bay has been cut sharply; the volume of its surface brines has been reduced also. As early as 1929, the annual flow of sea water into the bay was 25.8 km^3, as against the present figure of about 8 km^3. There have been temporary peaks on the generally downward discharge curve. Between 1938 and 1956, the bay depth has been reduced from ten to three meters; its water surface area from 18,000 to almost 10,000 km^2; and the brine volume from 103 to 28 km^3. The present volume of surface brine is about 25 km^3.

This contraction of the bay water surface has

FIGURE 1. Generalized map of Karabogaz-Gol

1 - ancient coastal swells and terraces; 2 - generalized 1930 boundary of brines;
3 - generalized 1956 brine boundary; 4 - exposed part of the upper salt layer;
5 - surface salt layer below the brine; 6 - gypsiferous saline (dry); 7 - 1956
brine isobaths; 8 - dry salines; 9 - generalized 1956 boundary of Caspian waters;
10 - generalized 1930 boundary of Caspian waters; 11 - exploration boreholes:
a - 1934-1935; b - 1954; c - 1951.

led to the formation of dry salines, from 30 to 50 km wide, along its shores. Karabogaz Strait itself has changed much in recent years.

In the thirties, it was 5.6 km long, 200 to 700 m wide, and up to 6 m deep, allowing the passage of boats to load mirabilite (Glauber salt) and thenardite and to carry the minerals to the Caspian ports [1]. The present Karabogaz Strait is about 10.5 km long and 100 to 150 m wide; it forms a peculiar "sea waterfall" about 4.0 m high.

Under the arid desert climate, the change in the Karabogaz-Gol water balance has lead to a concentration of its surface brines [12, 14]. The rise in this concentration since 1897 is shown in Table 1.

Present in the surface brine are sodium chloride, magnesium sulfate, magnesium chloride, potassium chloride, and other salts

Only Glauber salt was deposited from Karabogaz-Gol surface brines, prior to the thirties. The brine concentration has been rising since 1934, and the first precipitation of NaCl was observed in the summer of 1939.

Published in 1869 was a work by K. Behr [in German; based on erroneous data, it told of halite crystallization in Karabogaz-Gol and of the formation of salt deposits at its bottom. That communication has become part of all geologic textbooks and is cited by many even now

Up to 1938, the bay brine had about the sa

Table 1

Maximum concentration of salts in brines of the gulf (autumn composition)

Year	Density	Content of salts in %	Year	Density	Content of salts in %	Year	Density	Content of salts in %
1897	1.136	16.40	1936	1.208	25.20	1947	1.290	31.16
1909	1.149	18.10	1937	1.222	26.60	1948	1.290	31.73
1922	1.172	20.90	1938	1.230	28.20	1949	1.290	31.75
1930	1.175	21.30	1939	1.240	28.80	1950	1.292	31.48
1935	1.198	23.50	1945	1.275	31.77	1954	1.312	31.90
			1946	1.280	31.26			

omposition throughout its area. The post-1939 ummer precipitation of halite did not take place verywhere in the bay. In the western and outhern parts of the bay, where the brine was iluted by the incoming sea water, a precipitaon of carbonates and gypsum has been observed; however, there is no halite precipitaon, as of now.

The highest brine concentration prevails in he northern and eastern parts of the gulf, the rthest removed from the strait. As a result f halite crystallization here, the brine composition, in the summer, is quite different from at in the southern and western parts: the brine s low in Na and Cl ions.

A further rise in the brine concentration has ed to a simultaneous precipitation of halite and strakhanite [11]; in recent years, halite and psomite have been deposited in certain northrn parts of the bay.

At the present time, three zones can be idenfied in the gulf by their surface brine and its hysicochemical processes:

1. The dilution zone embracing the western nd southern parts of the bay (adjacent to the oast), from Ala-Tepe to the Yangi-Su spit. ere, the brine is not halite saturated, with irabilite precipitated in winter months.

2. The intermediate zone of metamorphism mbraces the eastern area of the bay, from the angi-Su spit to Point Linne, and the northestern coastal zone from Ala-Tepe to Solyanoy sland (it also includes the central part of the ay, according to the Expedition of the Institute f Organic and Inorganic Chemistry, the . S. S. R. Academy of Sciences). This zone is haracterized by summer precipitation of halite ith an addition of astrakhanite ($MgSO_4 \cdot Na_2SO_4 \cdot 4H_2O$) and epsomite ($MgSO_4 \cdot 7H_2O$) and winter recipitation of mirabilite ($Na_2SO_4 \cdot 10H_2O$) with n occasional addition of epsomite.

3. The zone of high metamorphism occurs

along the north shore of the bay, in the area of Solyanoy Island-Chagala-Malyy Linne. Taking place here is summer and winter precipitation of halite and epsomite (mixed) and autumn precipitation of epsomite. A slight solution of salts deposited during the year takes place in the spring.

It should be noted that there are no clean-cut boundaries between these zones. Their boundaries are unstable and dependent on the season, the volume of inflow, and the direction and intensity of prevailing winds which displace sizable masses of brine.

The determination of simultaneous deposition of different salt in the same salt basin but in different localities is of exceptional scientific and practical value. The brine composition in the gulf tends to change in the direction of eutonics.

Recent exploration in the Karabogaz-Gol has revealed three additional layers of mixed salts buried underneath the upper salt layer; they consist of halite, glauberite ($Na_2SO_4 \cdot CaSO_4$) and astrakhanite (Figure 2). The bottom salt layers are separated by horizons of gypsiferous carbonate oozes with a Caspian fauna. They are in turn underlain by ancient Caspian and Oligocene clays [7-9].

Thus, the Karabogaz-Gol has lived through four inundation stages and as many stages of dessication, undoubtedly related to periodic transgressions and regressions of the Caspian after the Würm glaciation of the Russian platform [10, 15, 16].

The geologic past and present of the Karabogaz-Gol are closely related to the Caspian. Its transgressions are marked by deposition of gypsiferous carbonate oozes in the bay; during the regressions, the oozes became more saline and became an accumulation site for mixed salts, depending on the concentration of the brines.

Table 2

Composition of buried interstitial brines in Karabogaz-Gol[1]

Data	Collection date	Sampling locality	Brine horizon	Sampling depth	Specific Weight
1	22/IX—1953	Test No. 306, southern part of the area of detailed survey (Kurguzul Cove)	II	8.0	1.153
2	"	Same	II	9.5	1.172
3	9/VII—1952	Test No. 106, central part of the detailed survey area (Sartas Bay)	II	4.5	1.203
4	"	Same	II	6.0	1.219
5	"	"	II	8.0	1.227
6	"	"	II	10.0	1.233
7	"	"	II	12.0	1.237
8	5/IX—1956	Test No. 150	II	6.0	1.223
9	"	Same	II	7.15	1.221
10	"	"	II	9.0	1.233
11	"	"	II	11.5	1.226
12	"	"	II	13.0	1.245
13	27/X—1954	Test No. 366, northern part of the detailed survey area (Sartas Bay)	II	4.5	1.231
14	"	"	II	6.5	1.236
15	"	"	II	8.0	1.246
16	"	"	II	10.0	1.254
17	3 IX—1954	Test No. 328, Chagala	II	6.5	1.267
18	"	"	II	8.0	1.270
19	"	"	II	10.5	1.273
20	18/X—1954	Test No. 338, Khodzha-Su	II	4.8	1.266
21	"	"	II	8.0	1.269
22	"	"	II	12.0	1.273
23	"	"	II	14.0	1.273
24	15/VII—1952	Test No. 106, central part of the detailed survey area (Sartas Bay)	III	18.5	1.237
25	"	"	III	20.5	1.243
26	7/VII—1956	Test No. 189	III		1.260

[1] Analyses performed at the chemical laboratory of the Karabogaz Geologic Exploration Party, the All-Union Institute of Halurgy (N.S. Garkavi and M.F. Kritskaya, Analysts).

The last 10,000 to 12,000 years have witnessed four transgressive-regressive cycles of the Caspian, corresponding to the four ooze horizons and to as many salt layers in the bay.

The first (surface) salt layer has been form ing since 1939, as a result of the present des sication of the bay. Deposition is still going with the present thickness up to 38 m.

(Table 2 continued)

Ion content in %							Salt content in %						
HCO₃	SO₄	Cl	Ca	Mg	Na		Ca(HCO₃)₂	CaSO₄	Mg(HCO₃)₂	MgSO₄	MgCl₂	NaCl	Total ions
0.11	3.62	8.36		1.19	4.96	18.24	—	—	0.13	4.54	0.98	12.58	18.23
0.11	4.20	9.18		1.15	5.83	20.47	—	—	0.13	5.26	0.27	14.80	20.46
0.05	2.64	13.87	0.02	0.91	8.53	26.02	0.07	0.01	—	3.29	0.97	21.68	26.02
0.04	2.69	15.00	0.01	1.03	9.07	27.84	0.05	—	--	3.37	1.37	23.05	27.84
0.04	3.46	14.93		1.51	8.50	28.44	—	—	0.05	4.34	2.43	21.63	28.45
0.03	4.05	14.78		2.15	7.47	28.48	—	--	0.04	5.07	4.40	18.96	28.48
0.04	4.36	14.55		2.34	7.11	28.39	—	—	0.05	5.46	4.82	18.07	28.40
0.04	2.86	14.48	0.02	1.17	8.54	27.10	0.05	0.01	—	3.57	1.76	21.71	27.10
0.04	3.01	14.43	0.02	1.26	8.41	27.16	0.05	0.01	—	3.76	1.95	21.39	27.16
0.04	3.70	14.40		1.75	7.80	27.69	—	—	0.05	4.63	3.17	19.84	27.69
0.05	3.52	14.16		1.73	7.59	27.05	—	—	0.06	4.40	3.29	19.30	27.05
0.08	5.21	14.08		3.04	5.88	28.28	—	—	0.09	6.52	6.71	14.96	28.28
0.04	3.65	14.47		1.45	8.40	28.01	—	—	0.05	4.57	2.04	21.35	28.01
0.05	4.42	14.30		2.09	7.45	28.31	—	—	0.06	5.54	3.76	18.96	28.32
0.08	5.30	14.04		2.66	6.64	28.72	—	—	0.1	6.64	5.09	16.90	28.73
0.08	5.82	13.85		3.04	6.05	28.84	—	—	0.1	7.29	6.07	15.38	28.84
0.14	7.44	13.32		3.44	5.75	30.09	—	—	0.17	9.32	5.99	14.61	30.09
0.11	7.94	12.77		3.06	6.34	30.22	—	—	0.13	9.95	4.03	16.11	30.22
0.09	8.43	12.49		2.84	6.80	30.65	—	—	0.11	10.56	2.70	17.28	30.65
0.14	7.44	13.25		3.51	5.56	29.90	—	—	0.17	9.32	6.26	14.11	29.91
0.15	7.58	13.55		3.88	5.13	30.29	—	—	0.18	9.50	7.56	13.06	30.30
0.14	7.73	13.46		3.89	5.13	30.35	—	—	0.17	9.68	7.48	13.01	30.34
0.14	7.71	13.48		3.90	5.11	30.34	—	—	0.17	9.66	7.52	12.99	30.34
0.03	4.75	14.61		2.76	6.54	28.69	—	—	0.04	5.95	6.07	16.53	28.69
0.06	5.62	14.23		2.93	6.40	29.24	—	—	0.07	7.04	5.87	16.26	29.24
0.02	6.69	13.49		2.58	7.07	29.85	—	—	0.02	8.38	3.47	17.98	29.85

This layer is represented by three principal minerals: halite, epsomite, and astrakhanite [6]. It covers about 75% of the bottom area. Its surface dips gently from shore to the center of the gulf and gradually plunges under the brine.

Its porosity is low (about 10%) and it is

Age	Generalized lithologic section	Thickness in m	Rock description
$Q_{IV}^{nx_2}$	+ 3 a / + 3 a + 3 a / 3 a +	1.5	Salts of layer I: halite (+), epsomite (e), astrakhanite (a)
$Q_{IV}^{nx_1}$	(gypsiferous ooze symbols)	4.0	Gypsiferous oozes with a fossil fauna.
	(symbols)	1.0	Gypsiferous sands
$Q_{III}^{hv_2}$	+ ۶ + / ۶ + ۶ ... (salt symbols)	10.0	Salts of buried layer II; halite (+), glauberite (g)
	(ooze symbols)		Oozes with gypsiferous sands
	(ooze symbols)	6.0	Gypsiferous oozes
	+ ۶ a / ۶ a + ... (salt symbols)	5.0	Salt of buried layer III: halite (+), astrakhanite (a), glauberite (g)
	(ooze symbols)	6.0	Oozes with mealy gypsum
	+ ۶ a / ۶ + a ... (salt symbols)	3.0	Salts of buried layer IV: halite (+), glauberite (g), astrakhanite (a)
$Q_{III}^{hv_1}$	(ooze / hatched symbols)		Oozes with mealy gypsum
	(hatched symbols)		Calcareous oozes and clays
Pg_2^{olig}	(symbols)		Oligocene clays

FIGURE 2. Generalized lithologic section of bottom sediments at the northwestern shore of Karabogaz-Gol, from data by the Karabogaz geologic exploratin party of the All-Union Institute of Halurgy.

saturated by interstitial brines which generate it.

The second salt layer was penetrated in 1951-1954 by numerous exploratory tests, below the Neo-Caspian deposits in Sartas Bay, Kurguzul Cove, and along the northwestern, northern, and eastern bay shore, at an average depth of 5.5 m.

This layer is separated from the overl[j] and the underlying ones by about 5 m of g[y]ferous carbonate oozes with a Caspian fau[na]

The second salt layer usually consists [of] halite and three glauberite beds and is ab[o] m thick, on the average. It thickens grad[ually] from the shore to the center. It is highly

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porous and is everywhere saturated with fossil brines.

Present along with pores in this layer are larger cavities; they have been observed in cores and have been detected by sudden pene- trations of the drilling tool.

The fossil brines which saturate this salt layer and a thin layer of gypsiferous sands at its top are at the second horizon of high- pressure buried brines.

This brine layer is characterized by its ex- tremely high permeability and brine-producing capacity, determined by its high porosity and the presence of cavities. Its percolation rate usually exceeds 2000 m/day, and the flow rate in tests is 400 to 500 m^3/hr.

The composition of the brines varies laterally and with depth. Sodium chloride and magnesium sulfate and chloride (Table 2) are prominent among the constituent salts. Present in rela- tively lower concentrations are salts of potas- sium, boron, bromine, etc. As a rule, these brines have a higher sulfate-ion concentration offshore than farther away from it and have a correspondingly higher mirabilite yield upon cooling. They become richer in sulfate and magnesium ions, with depth, and their density rises from 1.19 to 1.27, with a corresponding increase in total salts, from 25 to 30%. In the annual and secular cycles, buried brines, un- like the surface ones, are marked by stability of composition and temperature (15 to 17°C).

Brines of the second horizon are particularly important as raw material for sodium chloride as well as for the combined production of a number of other magnesium and potassium salts and microcomponents.

Beginning in 1955, the "Karabogazsulfate" combine has been completely converted for ex- ploiting a new king of halurgic raw material, buried brines of the second salt layer.

The third salt layer occurs at an average depth of 18 m. Its maximum penetrated thick- ness is 18.2 m, being about 5 m on the average. This layer is represented by halite, glauberite, and astrakhanite and is underlain by gypsiferous carbonate oozes which pass gradually to clay. The salt layer is porous and thoroughly saturated with brines at the third horizon of high-pressure buried brines.

Compared with the second, this brine hori- zon is characterized by low permeability and yield. Its brines are marked by a somewhat higher mineralization and comparatively uni- form composition. Their temperature is 16.4 to 17°C.

The fourth salt layer has been penetrated in a limited area, in the Kurguzul Cove and Sartas Bay. Like the third layer, it is represented by halite, glauberite, and astrakhanite. Its brines have not been studied.

Because of the Caspian Sea level drop, Kara- bogaz-Gol is now in a transition stage from a lagunal-lacustrine salt deposit to a deposit of fossil salts.

In order to maintain its function as an im- portant source of raw material (surface brines) it is necessary to regulate the inflow of sea waters by a lock gate. The minimum inflow for an optimum composition of surface brines should be established by additional hydrogeologic and hydrochemical studies.

The study of Karabogaz-Gol is going on. An understanding of its geologic past and present is of exceptional theoretical and practical interest.

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REVIEWS AND DISCUSSIONS

A FEW OBSERVATIONS ON THE ARTICLE BY
V. I. SMIRNOV AND T. YA. GONCHAROVA,
"GEOLOGIC FEATURES OF THE FORMATION
OF PYRITE DEPOSITS IN THE WESTERN
PART OF NORTHERN CAUCASUS"[1, 2]

by

V. V. Sviridov

We shall deal here only with Urup ore deposits.

1. There seems to be a radical divergence between our data and those of V. I. Smirnov and T. Ya. Goncharova. The main difference is that they place the Vlasinchikha deposit stratigraphically higher than the Urup proper and correlate it with the upper pyrite lens ("Upper") of the Urup deposit. The Skalistoye ore deposit is commonly believed to be lower than the Urup. However, a detailed study of numerous sections along the exploration lines of the Urup deposit has led us to the conclusion of stratigraphic identity of the Skalistoye and Urup deposits. The so-called intermediate composition tuffs are pyroclastic products of an intermediate to basic magma. Under the microscope, the diabase locally shows relict fragments of hornblende, with epidote "pseudomorphs" on them present in intermediate composition tuffs. In mineral composition, these diabases are chlorite-albite, seldom actinolite-albite, with a microlitic to intersertal texture. The intermediate tuffs consist of a secondary, twinned albite (occasionally oligoclase-labradorite) and a layered epidote-chlorite cement, up to 15% of the total.

2. V. I. Smirnov and T. Ya. Goncharova assign the Beskes and Urup deposits to the lower Paleozoic, after V. N. Robinson, who, as

[1] Nekotoryye zamechaniya k stat'ye V. I. Smirnova T. Ya. Goncharovoy "Geologicheskiye osobennosti obrazovaniya kolchedannykh mestorozhdeniy zapadnoy chasti severnogo Kavkasa".

[2] Izvestiya, Academy of Sciences, U.S.S.R., ser. geol., no. 2, 1960.

a matter of fact, believes them to be middle Paleozoic, i.e., Lower Devonian. He is quite specific in his description of the Devonian from the Laba and Urup region ("Geology of the U. S. S. R.", vol. IX, p. 79, 1947).

3. The position of the deposits in generalized stratigraphic columns is oversimplified. The Urup ore body, in many places, is known to be split up into 2 to 5 beds, in quartz albitophyre extrusives alone. In addition, present locally even between siliceous schists of the hanging wall and the ore, are thin (up to 5 m) members of quartz albitophyres. In the Vlasinchikha deposit, too, the ore bodies occur in acid lava and tuffaceous lava formations. The Skalistoye deposit too is made up of diabase and quartz albitophyre, with tuffaceous rocks extremely rare.

These facts demonstrate that the Urup ore bodies are associated with typical volcanic rocks.

4. V. I. Smirnov and T. Ya. Goncharova note that quartz albitophyres in the hanging wall of the Urup deposit were first chloritized then sericitized and silicified. Let us again turn to the facts.

Quartz albitophyres in contact with the Urup ores are largely silicified; chloritization is very rare. In contrast, the Vlasinchikha deposit quartz albitophyres in contact with the ores are strongly chloritized and are only slightly silicified. The ore-contact sericitization is altogether slight, with the sericite content in the lateral rocks hardly exceeding 10%, and usually less than that. The sericite development is more closely associated with regional metamorphism, because sericite is typical of highly schistose acid lavas and tuffs. In addition, the ore contact rocks, such as quartzitic and pyritic albitophyres ("secondary quartzites"), quartzitic rocks (metasiliceous shales), and chloritic rocks (metaquartzitic albitophyres and tuffs, in Vlasinchikha), are marked by their low schistosity; they are commonly massive.

If we correlate the Urup group of pyrite

deposits with the known Uralian deposits, with consideration given to the ore-contact alterations and the intensity of regional metamorphism, they will fall, by degree of metamorphism, between middle Uralian deposits, such as the Degtyarsk, and the Blyava nonmetamorphosed deposit in the south Urals. In its lateral rocks, the Urup deposit is more reminiscent of the Blyava [1, 2, 4, 5].

5. The two authors state that there is no evidence of metasomatic mineralization in either the Urup or the Beskes deposits. This is quite a surprise, what with the transition zones from massive to incrustation ores, the relicts of unaltered quartz albitophyres in the hanging wall of the Urup and other deposits, the metasomatic relationship of ore and non-ore minerals, to name only a few examples of metasomatism in the Urup deposits. We shall pause for one of them, namely the silicification of quartz amphibolites in that deposit, because of its practical importance in exploration.

The enclosing quartz albitophyres in the hanging wall of the Urup deposit, in direct contact with the ore, are altered to pyrite-quartz ores; farther away they change to "secondary quartzites" and finally to quartz albitophyres with a granoblastic, substantially quartzitic groundmass. These quartz albitophyres are typical lateral rocks. They differ from felsitic quartz albitophyres in chemical composition, as well. Granoblastic quartz albitophyres occur in units tens of meters thick, with felsitic quartz albitophyres present in them apparently as relicts. A gradual transition from the granoblastic to the felsitic variety can be seen under the microscope. Comparatively less common are microlitic quartz albitophyres, occurring away from the ore bodies.

The quartz albitophyres usually are euporphyritic rocks, with phenocrysts containing quartz, as a rule. The felsitic quartz albitophyres locally carry albite tablets also, occasionally "grown together" at the base. Albite phenocrysts are typical of microlitic groundmasses. A granoblastic groundmass consists of fine (0.03 to 0.1 mm) isometric quartz grains, locally with some feldspar, with chlorite-sericite developed in the mesostasis. Somewhat better developed microscales of chlorite and sericite are present in felsitic quartz albitophyres. The microlitic groundmass is represented largely by microlites of twinned albite and by quartz grains.

6. In conclusion, we take up the subject of "ore pebbles".

The two authors interpret them as volcanic-sedimentary [6, 7] formations similar to tuffaceous rocks. R. P. Tuzikov [8] calls them "metasomatic". We submit still another name for them. According to geologic reports of the Urup Expedition, isolated "ore pebbles" have been found only in two boreholes: No. 47, at 69.8 m; and No. 240, at 248.7 m. We have n seen any "ore pebbles" in the preserved cores from those tests. Nor have we seen them in the many other tests we have studied. Locall the enclosing rocks do carry ground-in "ore pebbles" associated with fault zones.

Thus, it must be admitted that these "ore pebbles" require additional study.

In these observations of ours we have made reference to field data of the geology and part cularly the petrography of the Urup deposits, not considered by V. I. Smirnov and T. Ya. Goncharova in their substantiation of the exhalation-sedimentary origin of north Caucasia pyrite.

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ON THE OBSERVATIONS BY V. V. SVIRIDOV ABOUT MY ARTICLE, "CERTAIN GENETIC FEATURES OF THE URUP PYRITE DEPOSITS (NORTHERN CAUCASUS) AND ON V. I. SMIRNOV'S AND T. YA. GONCHAROV'S VIEWS OF THE THEORY OF AN EXHALATION-SEDIMENTARY FORMATION OF NORTHERN CAUCASIAN PYRITE DEPOSITS [3]

by

R. P. Tuzikov

In V. V. Sviridov's observations on my article [2], published in this magazine, No. 3, 1960, the author, largely on the basis of microscopic data and of some field observations, presents an erroneous interpretation of my data.

It is rather surprising that V. V. Sviridov, after a fairly extensive study of the Urup dikes (mostly microscopically), including those occurring in the ore bodies, has failed to notice their schistosity and dynamometamorphism. He interpreted them as contact metamorphic and even assumed their genetic relationship with the sources of mineralization (as clearly stated in an article by I. Ya. Baranov and V. V. Sviridov) only to arrive at a surprising conclusion (for no good reason) that these dikes were post-ore and dynamometamorphosed. In so doing, he contradicted the results of his own study of many years.

To take up his observations and conclusions:

1. V. V. Sviridov believes that dikes of altered rocks, occurring among pyrite ores,

"are more or less schistose and seldom massive in the middle". He then concludes that the dikes are post-ore, having undergone a regional metamorphism, together with the ores.

If he had studied these dikes in mine faces as well as in the Skalistoye deposits, he would have seen plainly that a dike in ores, even in its peripheral part, is not schistose but rather massive, strongly quartzitic, only slightly impregnated with pyrite and chalcopyrite, with its peripheral part slightly chloritized and therefore greenish. It follows that such a vein is ore-contact metamorphosed, possesses typically hydrothermal metasomatic zones, is utterly devoid of shearing schistosity planes, and cuts the enclosed schistose rocks either at an angle or normal to their schistosity and occurrence, cleancut evidence that this dike was formed in already schistose rocks.

In central parts of the Urup deposits, the dikes are almost completely replaced by carbonate and have inherited the primary texture of rocks and minerals (this phenomenon is seen under the microscope). Larger bodies of a mineral (biotite?), oriented with the dike trend and replaced by calcite are also present here. It is possible that it is this that has suggested the dike's "schistosity" to V. V. Sviridov. On the other hand, peripheral parts of the dikes are replaced by chlorite which also fringes them. The chlorite aggregates here are foliated, oriented along the replaced contact and with the dark mineral of the dike. They are impregnated with chalcopyrite and to a smaller extent by pyrite, along the intramineralization shearing fractures of a subsequent mineralization stage. These fractures are especially well developed in the weakest chloritized segment of the dike, thus giving it a schistose aspect.

Contact alterations in the dikes, quite similar to metasomatic contact alterations in the enclosing rocks, are in complete correspondence with mineralization stages of the ore deposit (primarily calcite, followed by chlorite-calcite, or quartz-chlorite, etc.), except for those features determined by the physical composition of the dike rock; these alterations are expressed in a metasomatic zonation which indicates their hydrothermal nature. No similar or any other zonation has been observed in definitely dynamometamorphosed rocks, at least in the area under study.

V. V. Sviridov himself writes that these dikes "are seldom massive in the middle". Now, such a phenomenon is hardly possible in comparatively thin dikes, regardless of the strength and thickness of individual lithologic varieties, in the presence of all old volcanic rocks. Consequently, these dikes should be regarded as pre-ore, ore-contact metamorphosed, and formed in already schistose rocks.

[3] O zamechaniyakh V. V. Sviridova po povodu moyey stat'i "nekotoryye cherty genezisa Urupskikh kolchedannykh mestorozhdeniy (severnyy kavkaz)" V. I. Smirnova i T. Ya. Goncharovoy o teorii ekshalatsionno-osadochnogo obrazovaniya severokavkazskikh kolchedannykh mestorozhdeniy.

In his belief in a regional metamorphism of the ore bodies and dikes, V. V. Sviridov overlooks the significance of slightly brecciated ores near the dikes' contact (he observed them only under the microscope and he regarded them as evidence of a post-ore origin of the dikes). Indeed, if both the dikes and ores had undergone regional metamorphism, the intensive alteration would have completely obliterated such slight "premetamorphic" brecciations, visible only under the microscope. As to the so-called "squashed" quartz-calcite aggregates (which he regards as formed in the ore during the dike intrusion), they are unevenly distributed throughout the ore body and represent relicts of replaced metamorphic rocks as well as intramineralization formations compressed in intramineralization shifts, although the latter usually have a comparatively fresh aspect.

Thus, these views of V. V. Sviridov on the age of dikes in pyrite ores do not correspond to field data and are based on their misinterpretation.

Present along the Bol'shaya Laba, in an adjacent area, are outcrops of schistose intrusives (Urushten complex). It is therefore not impossible that the so-called schistose intrusives of that complex are also present in the Urup area; however, our dikes are younger.

2. V. V. Sviridov asserts that the so-called "pre-ore thrusts" have often been observed in the ore bodies themselves; consequently, he regards them as post-ore. In so doing, he does not discriminate between two systems of noncontemporaneous thrusts.

Pre-ore thrusts are altogether missing in the ores; they displace only the pre-ore dikes, with chalcopyrite developed along the displacement planes. The same metasomatic zonation is present along pre-ore thrusts in pre-ore dikes of altered rocks as along the dike-ore contacts; the dike rock is replaced symmetrically with the pre-ore thrust contact, by chlorite with pockets of metasomatic quartz and with chalcopyrite veins. Pre-ore thrust flexures, up to 0.8 m, which deform the schistose rocks, are cut by the ore contacts, thus clearly establishing their pre-ore origin.

The post-ore thrusts are steplike, with displacement in the ore bodies from a fraction of a millimeter 3 cm (in contrast to a range of tens of centimeters to several meters for preore thrusts), and are developed on an older cleavage system; the usual direction of dip is opposite to that of the pre-ore thrusts; they have chalcopyrite developed along them; and contact alterations in the enclosing rocks are missing.

3. V. V. Sviridov notes that "a detailed study" does not reveal any fragments of metamorphosed rocks in the nonschistose zone of the secondary quartzites. He does not mention the fact that this zone is massive rathe than schistose (which, incidentally, indicates th absence of metamorphism in contact rocks, and consequently in the ores). His assertion that th ore-contact secondary quartzites change gradually to siliceous metashales is erroneous. On the contrary, the contact between secondary quartzites and the enclosing rocks is extremely sharp.

4. My article carries a photograph of a core in which a quartz vein unconformably cuts the schistose rock. This vein is displaced by a chlorite vein with pyrite. It is therefore reasonable to assume that the ore vein is younger than the quartz vein, and that much younger than the schistosity of the enclosing rocks. In his criticism, V. V. Sviridov states, "It appears from the photograph... that the quartz vein has an uneven contact line and wedges out. As observed in the deposit, such veins are metamorphosed; we believe them to be of an Alpine type... the concept of their being younger than the schistosity loses all meaning."

In reply, it can be said that, first of all, the Alpine type veins, instead of being metamorphosed, are filled with excellent crystals; their average composition corresponds to that of the enclosing rocks; and their trend is that of the rocks (and the schistosity), but their dip is approximately at right angles to schistosity. The well-formed crystals in the Alpine-type veins are not schistose and the wall segments are even rather than displaced with the schistosity. This means that the veins were formed in the last stages of dynamometamorphism when the stresses were higher than the critical strength of the rocks, for plastic deformation and schistosity. Even in that case, the fact of an Alpine vein being cut by a younger ore vein would mean that the ore vein is younger than the schistosity of the enclosing rocks. Second, no all veins represented by mineralized tension fractures are of an Alpine type. Third, the vein in the photograph is filled by massive, no schistose "milky" quartz; according to micro scopic data, it is also not metamorphosed to the same extent as the enclosing rocks. This vein like similar veins in the deposit, has nothing common with the Alpine-type veins (undiscove by anybody, as yet, in Urup).

It follows, then, that the vein in question i younger than the quartz vein and certainly younger than the schistosity of the enclosed rocks.

V. V. Sviridov assigns all these ore veins the so-called metamorphic veinlets (because their small thickness; i.e., 1 to 3 cm, accor ing to him). We would point out that there a veins of a similar composition in Urup; these veins are tens of centimeters thick, and they

cut quartzitic and schistose rocks at right angles to their schistosity and strike. However, the ore veins in question cannot be assigned to those metamorphic veinlets, because they also occur in the absence of ore bodies; consequently, there could be no question of their "redistribution" as is the case with metamorphic veins.

5. V. V. Sviridov doubts that the hanging wall of the deposit, made up of copper and copper-zinc ores, has been formed in a replacement of its siliceous metashales. He believes (if we understand him correctly) that the ore body has been formed as a result of the filling of a fracture, rather than as the result of metasomatism. It can be said in this respect that relicts of unreplaced siliceous metashales were found in that part of the ore deposit, in 1951, by myself and by V. A. Zavaritskiy and N. V. Ivanov, working independently.

6. Considering that V. V. Sviridov associates the fracturing of pyrite in ores with regional metamorphism, it is strange to see him cite as evidence for ore metamorphism the fact that pyrite is but slightly fractured in Urup, even less so in Vlasinchikha, and practically not at all in the Skalistoye deposit. Such a difference in the fracturing of pyrite occurring in similarly sheared rocks, but from different localities suggests rather that this fracturing is associated with intra-ore shifts in mineralization, rather than with regional metamorphism.

Thus all post-pyrite mineralization stages were developed more intensively in Urup; accordingly, the pyrite is most fractured here; it is less so in Vlasinchikha (with a consequent smaller number of ore varieties. In the Skalistoye deposit, the chalcopyrite mineralization stage prevailed, on the whole; in addition, chalcopyrite ores occur here separately from pyrite; for these reasons, the pyrite fracturing here is not characteristic.

It should be noted in passing, that V. V. Sviridov's "observations" err in reporting: I have definitely disclaimed the statement that these Paleozoic volcanics are possibly older than Devonian.

An article by V. I. Smirnova and T. Ya. Goncharova [2] also contains some criticism of our views on the geology of the Urup deposits.

All the field material used by those authors in support of their statements consists of pebble-like pyrite deposits found in intermediate tuffs above the ore body. It appears from the article that the authors themselves have not seen them but have borrowed their description from various reports.

Findings of lenticular pyrite inclusions, locally reminiscent of pebbles, both above and below the ore body, are described in my article

[4]. Upon a personal request from T. Ya. Goncharova, even before publication, I prepared for her a number of specimens of the so-called "pyrite ore pebbles" from rocks underlying the ore. However, T. Ya. Goncharova never got around to looking them over; instead, in her joint article with V. I. Smirnov, she cast doubts on the authenticity of my material. Furthermore, notwithstanding their assertion on the absence of mineralization in intermediate composition tuffs, with its so-called "pebbles" which they regard as evidence of the lack of mineralization, here, and a basis for their drawing the upper mineralization age boundary, we must say that there are quite a number of pyrite veins in those tuffs, but the "pebbles" are quite rare.

This also is the conclusion of many geologists from various organizations who studied that section, after the publication of an earlier paper by V. I. Smirnov and T. Ya. Goncharova [3].

Militating strongly against an exhalation-sedimentary origin of the Urup pyrite deposit are ore-contact alterations of the enclosing rocks, forming metasomatic zones about the ore body. These essentially quartzitic zones, the so-called "secondary quartzites", and an essentially chloritic outer zone are characteristic of the hanging wall rocks. The floor is characterized by a quartz-pyrite zone with the ore body gradually changing to vein mineralization and presenting evidence of hydrothermal metasomatism.

The same is true for ore-contact altered dikes, as described in more detail, above. The mineral relicts typical of the enclosed rocks unequivocally suggest a hydrothermal-metasomatic origin of the ore body.

It is to be noted that the Kyzyl-Kol deposit (Khudes), too, is made up of both massive ores and veinlet-inclusion varieties, typical hydrothermal formations. The metamorphic origin of these veinlets cannot be assumed, because the ore-bearing section (of the Lower Carboniferous Karachayev series) has not undergone regional metamorphism and is not schistose, although T. Ya. Goncharova asserts that she has observed veins of an Alpine type there.

In citing their geologic data on Urup and Kysyl-Kol, V. I. Smirnov and T. Ya. Goncharova fail to mention specifically which locality they have in mind, so that only a reader familiar with local geology can made a correct guess.

Without denying the possibility of an exhalation-sedimentary, and even of a purely sedimentary, origin for the pyrite deposits, we believe that there is no evidence of such an origin in any of the presently known ore bodies or ore showings occurring in the Paleozoic volcanic section.

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REVIEW OF "THE LOVOZERO ALKALIC MASSIF" BY K. A. VLASOV, M. V. KUZ'MENKO, AND YE. M. YES'KOVA[4]

by

T. N. Ivanova and A. V. Galakhov

The Lovozero alkalic massif is one of the most peculiar and interesting geologic features, not only in the Kola Peninsula but in the world. Its curious petrography and the parageness of its rare metals, including those first discover-ed in the Lovozero tundra, along with the dis-tinctive geochemistry of its geologic processes, have long attracted the attention of geologists, mineralogists, geochemists, and crystallo-chemists.

A voluminous literature deals with this

massif, such as the monographs in various fields by N. A. Yeliseyev, O. A. Vorob'yeva, and V. I. Gerasimovskiy. The publication of this collective comprehensive study of the mas-sif is a further advance in our knowledge of the mineralogy, geochemistry and origin of alkalic intrusions.

The monograph, "Lovozero Alkalic Massif", a total of 623 pages, 257 illustrations, and 201 tables, is a capital work setting forth the re-sults of many years of study of the geology and chemical and mineral composition of the Lovo-zero tundra rocks, with a detailed analysis of pegmatite formations extensively developed in the massif. Emphasis is put on a monographic description of minerals occurring in its several petrographic complexes. This includes all minerals discovered in the Lovozero region, in-cluding many rare species. The geochemistry of individual components of the massif is con-sidered in detail, as is the geochemistry and origin of the massif as a whole.

A comparative description of the composition of all types of the Lovozero massif rocks, as given in the first part, along with empirically established regularities in the distribution of minerals and rare elements, has enabled the authors to determine the relations between the distribution of the two groups; this is of both theoretical and practical value as an exploration guide.

A careful study of the constitution and min-eralogy of pegmatites in this massif, as pre-sented in the second part, has helped to identify the factors responsible for their variety, thus making a valuable contribution to the problem of the origin of pegmatites in general, and of alkalic pegmatites in particular.

The third and the largest part of the mono-graph deals with minerals of the Lovozero massif, in all their characteristic variety. Over 100 minerals are described in detail; about 50 of these are rare, marked by the com-plexity of their component elements. This description has been used as a basis for estab-lishing the regularities in mineral distribution and in determining the various paragenetic as-sociations typical of the massif. The authors have established the stage nature of the min-eralization processes and have indicated the crystallization point for each rare metallic min-eral, in the course of formation of the massif. All these data have enlarged our knowledge of the mineralogy of alkalic intrusions and are a major contribution to the science of mineralogy.

Part four, the geochemical genetic part, presents chiefly the authors' original data on the geochemistry and origin of the massif. A painstaking study of the chemical composition and distribution of rocks and minerals has en-abled the authors to determine its peculiarities

[4] O knige K. A. Vlasova, M. V. Kuz'menko i Ye. M. Yes'kovoy "Lovozerskiy shchelochnoy massiv".

and the empirical regularities in the distribution of the 67 component elements. According to the authors, the main factors determining the layered structure of the massif are a rhythmic crystallization differentiation and an emanation process. As noted before, these conclusions are important both theoretically and practically, in exploration.

The authors demonstrate the great importance of crystallization differentiation and of emanation processes, not only in the Lovozero massif but in the formation of alkalic magma in general, in the progressive series of magmatic processes, a momentous theoretical achievement.

This monograph is of unquestionable value in the understanding of the Lovozero massif as well as of other alkalic massifs of the U. S. S. R. and other countries; the list of such massifs has been growing with every year. It also is of value in prospecting for minerals associated with such massifs.

Now that the use of rare elements for the purposes of the national economy is becoming ever more important, the publication of this book by K. A. Vlasov, M. V. Kuz'menko, and Ye. M. Yes'kova, is quite timely.

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CHRONICLE

FIRST ALL-UNION CONFERENCE ON
GEOLOGY AND METALLOGENY OF THE
PACIFIC BELT[1]

by

Yu. M. Pushcharovskiy

The problems of stratigraphy, tectonics,
[ign]eous activity, and metallogeny of the Pacific
[bel]t have been given particular attention by
[Sov]iet geologists. It has often been stated that
[the] geology of coastal Pacific provinces, be-
[sid]es its regional interests, is of great im-
[por]tance in determining general and essential
[reg]ularities in the structure and evolution of
[the] earth. Specifically, this is the place to
[stu]dy present geosynclinal processes in all their
[var]iety, along with the relationship between con-
[tin]ental and oceanic structures, in time and
[spa]ce.

[B]esides, this belt is known to contain major
[dep]osits of valuable minerals, such as tin, gold,
[lea]d, tungsten, mercury, fluorite, etc., es-
[sen]tial for broad planning in the national econ-
[om]y of our country.

[T]his is why the First All-Union Conference
[on t]he Geology and Metallogeny of the Pacific
[Belt], called by the U. S. S. R. Academy of Sci-
[enc]es and the Ministry of Geology and Mineral
[Con]servation, at Vladivostok, in September of
[196]0, aroused such a great interest among the
[var]ious geologic organizations, both central and
[loca]l.

[T]he Conference was held September 26
[thro]ugh October 2, with over 200 delegates from
[many o]rganizations participating. It owed its suc-
[ces]s to the work of the Organization Committee
[(Ye. A.] Radevich, Chairman) and to the coopera-
[tion] of Party and Soviet Organizations of the
[Reg]ion (V. Ye. Chernyshev, First Secretary of
[the] Maritime Regional Committee, C. P. S. U.).

[1] Pervaya vsesoyuznaya konferentsiya po geologii
[me]tallogenii tikhookeanskogo poyasa.

During a seven-day field trip following the con-
ference, the participants were introduced to
geologic sections of the Sikhote-Alin mountain
system and of the Hankai trough (leader: I. I.
Bersenev, Chief Geologist of the Maritime Geo-
logic Administration).

Prior to the Conference, the Organization
Committee published two issues of abstracts of
papers by 92 authors, and an excellent guide-
book for the field trip, of considerable scientific
interest, besides being a reference.

The following topics were of prime interest
for the Conference:

1) general geology and metallogeny of the
Pacific belt;

2) geology and metallogeny of individual ore
provinces (Maritime, Amur Region, Trans-
baykalia, Northeast U. S. S. R., and some others);

3) relation of mineralization to igneous acti-
vity and faults.

The papers on general topics were dis-
tinguished by their interesting hypothetical
schemes.

The main metallogenic features of the Pacific
belt within the U. S. S. R. were discussed by Ye.
A. Radkevich, jointly with M. I. Itsikson and
V. T. Matveyenko. Their thesis is that the dis-
tribution of metallogenic Pacific belts has been
affected primarily by ancient major fault sys-
tems. One of them runs sublatitudinally from
the Aleutian deep trench to a fault separating the
Stanovoy Range and the Aldan Shield, and farther
on, along that fault; another fault, also lati-
tudinal, is present in the Yangtze basin (China);
finally, a third one, with a general Kurile trend,
corresponds to the volcanic belt extending along
the Asian continent from Chukotsk Peninsula as
far as southeastern China. These systems are
called transcontinental. The authors believe
that they originated at different times: the sub-
latitudinal in the Precambrian, as the result of
splitting up in an ancient platform; the others at
the beginning of the late Paleozoic, in connection

with the initiation and development of the Pacific trough.

Generally associated with the sublatitudinal systems are auriferous provinces. The volcanic belt (within the U. S. S. R.) is characterized chiefly by concentrations of tin, lead and zinc. Ye. A. Radkevich presented a large and demonstrative layout of a metallogenic map for the entire Circumpacific Belt.

Tectonic concepts similar to those were voiced by A. M. Smirnov whose thesis was that geosynclinal troughs, including the eugeosynclinal, had been formed as a result of "activation" in the vast expanse of the northeastern shelf of an ancient Chinese platform.

L. I. Krasnyy, P. N. Kropotkin, and G. P. Volarovich presented a general scheme of tectonic relationships of the eastern U. S. S. R. According to them, the following elements should be differentiated in the Mesozoic and Cenozoic folded provinces of the Pacific belt:

1) an outer zone of essentially Mesozoic folding (Verkhoyana-Kolyma, Chukotsk, Mongolo-Okhotsk, and Sikhote-Alin);

2) an inner zone of essentially Cenozoic folding (Sakhalin, western and central Kamchatka, and the Koryak Highlands);

3) the present-day mobile geosynclinal zone (eastern Kamchatka, Kuriles, and the deep troughs).

In this framework, an attempt is made to subdivide the Cenozoic folded zone, as generally understood, into two independent zones equivalent to Mesozoic systems of the eastern U. S. S. R. It appears, however, that this concept has not been adequately substantiated. The old concept was also represented at the Conference by P. N. Kropotkin's tectonic map of the eastern U. S. S. R., on a scale of 1:2,500,000. According to that concept, there are two principal foldings in the Circumpacific Belt: Mesozoic and Cenozoic. It is obvious that this important subject calls for additional study.

An interesting point brought up was the development of a thick Upper Cretaceous section in Sikhote-Alin, which is supposed to associate the latter with Sakhalin.

Exhibited was a preliminary draft of the tectonic map of Asia, 1:5,000,000, prepared at the Geological Institute of the U. S. S. R. Academy of Sciences, in 1960. A report on the map by A. L. Yanshin, N. P. Kheraskov, and Yu. M. Pushcharovskiy (read by N. P. Kheraskov) contained an exposition of the principles on which it was compiled as well as some conclusions arrived at from the map. The tectonic differentiation had been made on the basis of the age

of folding, arrived at through formation anal ysis. Such a differentiation has led to the ne essity of assuming the presence in Asia of e and late Caledonian rocks; it also has sugges the expediency of a similar differentiation fo Hercinian and Mesozoic rocks.

In a paper of his own, N. P. Kheraskov as serted that the main Eurasian folded structu is a belt separating the Russian and Anabar platforms from the Gondwana platform syste A giant branching of that belt takes place in easterly direction where it joins the structu of a meridional Pacific belt. Tectonic proce in these two belts were asynchronous, a fact important in the understanding of the general features of igneous activity and metallogeny.

The structural position of the northern se ment of the Pacific belt, with relation to tec tonic elements of the Arctic sector of the ea was discussed by Yu. M. Pushcharovskiy, on basis of an analysis of the 1:7,000,000 tecto map of the Arctic. He came to the conclusi that the damping of Mesozoic movements in northern Asia and Alaska takes place within Arctic Archipelago of Canada. He presente evidence of two types of Mesozoic developme Nevada and Kolyma. The Nevada type had b characterized by eugeosynclinal developmen since the most ancient times; this is not tru the Kolyma type.

Ye. T. Shatalov, representing a group of authors, spoke on the main features of ignee activity in the northwestern part of the Paci belt. He outlined the magmatic phenomena folded provinces of Soviet East Asia: the Mongolo-Okhotsk, Verkhoyano-Chukotsk, Sikhote-Alin, and a province of Cenozoic fo extending from the Koryak Highlands to Sak According to the collective authors, the ger evolution of tectonomagmatic "cycles" in th provinces broadly corresponds to Yu. A. Bi bin's concepts. It was also stressed that a shift of these tectonomagmatic zones towar Pacific trough has been going on during all Hercinian history; it has been accompanied progressively higher basicity of igneous co plexes, in the same direction. In agreeme with S. S. Smirnov, the authors note a pre dominance of acid intrusions in the outer P belt zone, with the accompanying gold and metal mineralization (with a low copper co tent); the inner zone is characterized by ul basics and by basic intrusions with their c nickel, chromium, mercury, etc.

It can be said, on the whole, that these on the general geology and metallogeny of nental structures in the Pacific belt have d strated the importance of current problem tackled by Soviet geologists. At the same further and better substantiated conclusior require more extensive field data, includi those on the rest of the Circumpacific Belt

Most papers were on regional geology and
metallogeny of ore provinces and areas.
ch interest was aroused by the papers of N.
Belyayevskiy, Yu. Ya. Gromov, and L. A.
skakov, on the tectonic development of
hote-Alin, accompanied by a series of paleo-
tonic maps; also by N. I. Bersenev's paper on
tectonics of the Maritime Province. The
hors of the first paper noted that, beginning
he late Paleozoic, the western rim of the
ific had been a locus of subsidences inde-
dent of the earlier structural plan but con-
mable with the present outline of the Pacific
ugh. Specifically, the Sikhote-Alin geanti-
ne, probably Carboniferous in age, was
med on the site of a folded structure in an
ly Paleozoic geosynclinal province (Riphean-
mbrian). Stressed in the development of
ntral Sikhote-Alin was the importance of a
ep fault separating the main Sikhote-Alin
iclinorium from the central synclinorium.

N. I. Bersenev presented quite a complete
ologic picture of structural elements in the
ritime Province, on the basis of recent study.
noted that the general tectonic scheme of
gion, presented by P. N. Kropotkin in his time,
mains on the whole, valid. According to the
hor, the youngest geosynclinal formations in
Hankai massif are Cambrian in age (with
y the Lower Cambrian proven, for the pre-
nt). These are tightly folded sandstones,
les and siliceous shales, and limestones.
osynclinal Devonian beds have been tenta-
ely identified in the Grodekov zone. The
ubikhin synclinal zone represents a Mesozoic
ugh developed in the marginal part of the
nkai massif. A geosynclinal development in
central synclinorium persisted till the
onian. N. I. Bersenev has identified a major
ep fault south of the Hankai massif, trending
latitudinally and cutting off a peculiar South
ritime zone.

Equally interesting was a paper by V. A.
rmolyuk on the structure of the Amur pro-
ce and on regularities in the distribution
re of industrial minerals. He demonstrated
association of iron ores, aluminum raw
terial, and graphite, with pre-Riphean struc-
es, and of iron and manganese ores with
phean rocks. Also present in Paleozoic for-
tions are manganese deposits, while the gold
lds of Zeya, Niman, and Kerb basins are as-
ciated largely with intrusions of that age.
wever, most deposits of gold, tin, mercury,
gsten, polymetals, and molybdenum are
sozoic in age. Upper Cretaceous granitoids
represented as specialized ore carriers
ponsible for major commercial tin deposits.

Geology and metallogeny of the northeastern
S. S. R. was dealt with in papers by V. T.
tveyenko and K. V. Mokshantsev (represent-
a group of Yakutian geologists), V. A. Titov
behalf of Magadan geologists), I. Ye.

Drabkin, S. M. Tilman, and others. These
papers were mostly in the field of regularities
in the distribution of gold, tin, and mercury
deposits throughout that immense and economi-
cally important region. There are two schools
of thought on the origin of gold deposits. Ac-
cording to one (V. T. Matveyenko, Ye. T.
Shatalov), they are associated with the so-called
"pre-batholith" formation of minor-fracture in-
trusions, Upper Jurassic to Lower Cretaceous
in age. According to the other, the formation
of auriferous ore deposits is a fairly complex
multiphase process. For instance, gold min-
eralization in the Anyuy-Chukotsk zone oc-
curred largely during the Early Cretaceous
(S. M. Tilman). It is quite evident that special
attention should be paid to this extremely im-
portant subject in the future.

Much criticism was encountered by I. Ye.
Drabkin's assertion that the Kolyma median
massif represents an ancient platform (L. A.
Snyatkov, N. P. Kheraskov, and Y. T. Shatalov).

The important province of Transbaykalia
was dealt with in a collective paper by the
VSEGEI staff (V. S. Kormilitsin, N. I. Tik-
homirov, N. V. Shtal, D. M. Shilin, and A. D.
Shcheglov), also in papers by V. N. Kozerenko
and V. V. Starchenko, D. I. Gorzhevskiy, F. I.
Wolfson and A. V. Druzhinin, and a few others.

Individual controversial topics were dis-
cussed against the background of a general geo-
logic and metallogenic analysis of that province.

M. S. Nagibina spoke on the structural posi-
tion of Mesozoic granite intrusions within the
Mongolo-Okhotsk belt. These intrusions are
associated with peculiar superimposed troughs
characterized by a deposition of thick conti-
nental and marine molasse, land flows of inter-
mediate to acid lavas, granitoid intrusions, and
a development of brachysynclinal and boxlike
tectonic forms complicated by faults. This type
of trough is common in eastern Asia; it has been
termed "Amur-Chinese", by the author.

G. P. Volarovich presented his view on the
junction of the Pacific and Mongolian structures
and on the distribution of gold-bearing regions
throughout the Far East. Certain problems of
the tectonics and metallogeny of China and
Korea were discussed in papers by M. G.
Organov and K. B. Il'in.

There is no room here even for a glimpse of
all the papers and communications on this sub-
ject, except to say that they contain a large
amount of the most recent field data as well as
numerous and interesting conclusions to be con-
sidered in future studies.

The general relationship between mineraliza-
tion and igneous activity in the Pacific belt was
discussed in a paper by M. A. Favorskaya in

cooperation with M. G. Rub, Ye. I. Dolomanova, and V. A. Kagay.

In summarizing the studies of the last few years, the authors stress that specialized intrusive metalliferous complexes are present in various geologic systems, from the Paleozoic to the Tertiary. They are multiphase, marked by a wide development of hybridism. Significantly, these regions have inherited their leading mineralization; at the same time, the totality of their geochemical features has been affected by their differences in age and structural position. The several regions are marked by a single sequence in the alternation of magmatic phases and stages of hydrothermal activity. Separation of the bulk of ore-bearing intrusions took place after the formation of the youngest alaskite intrusions. A natural series has been established for different types of mineralization, with transitional types in between (greisen and cassiterite-quartz mineralization, followed by cassiterite-quartz-sulfide, cassiterite-sulfide, essentially polymetallic, and fully polymetallic with antimony sulfides). This series is traceable in time as well as in space.

Three points of view were presented on the interesting and controversial problem of island arcs.

The first, developed in the paper by V. V. Belousov and Ye. M. Rudich, "On the Place of Island Arcs in the Over-all Structure of the Crust", as well as in A. V. Goryachev's paper on Kamchatka and the Kuriles, explains the origin of the island arcs by oceanization of the crust. We shall not pause for them here: they have been published in Soviet Geology, No. 10, 1960.

According to the second view, presented by P. N. Kropotkin, the critical factor in their origin is a horizontal movement of crustal blocks, due to extension (stretching). For example, the Japanese island arc has shifted, according to P. N. Kropotkin, some 400 km east of the continental structures.

A comparison of these two papers demonstrates the broad range of interpretation of the geologic structure of Japan.

The third view was presented by G. B. Udintsev. He connects the origin of island arcs with the general evolution of the crust at the ocean bottom. This process is reflected in a single evolutionary series of tectonic formations. The simplest of them are the so-called "swells", flat folds in the basalt layer, more or less complicated by faulting and supporting volcanic superstructures. The more complex structures are also represented by gentle folds in the basalt layer, now at the base of a thick volcanic, locally block-folded range, and associated with a deep subsidence of the oceanic trough (Marianas and Idzu-Bonin island arcs). Still more complex structures are formed by two anticlinal uplifts, the outer one of which is now characterized by a continental crust and by a block-folded structure (Aleutian and Kurile-Kamchatka island arcs). The Pacific thalassocraton appears to be growing in concentric belts of island arcs. This process, however, is uneven and discontinuous.

All this shows that the problem of island arcs calls for more study.

Even this brief account is enough to show the scope of the papers read before the conference. Despite the short time allotted to each (15 to 25 min), their number (over 60) prevented any extensive discussion; this, in our opinion, is a shortcoming in the work of the Conference.

The closing meeting adopted an extended resolution recommending the main trends for future study of the Pacific belt, and particularly the Soviet segment. One of the important organizational decisions is the recommendation to create a standing committee in the Presidium of the Siberian Section of the U. S. S. R. Academy of Sciences, for a coordination of work in the geology and metallogeny of the Pacific belt.

A few words on the field trip. Our main impression was of the extensive study and development of mineral resources, done by local geologic and mining organizations. The participants were met everywhere by industry geologists who did their best in presenting the information on deposits, and outcrops.

The main overland trip was from Tetyukhe Cove to the Voznesenskiy ore center. In this way, we have crossed all structures of Sikhote Alin and examined the sections of the Hankai front trough and rocks of the Hankai massif. It should be noted that Maritime outcrops are generally rather poor, often making it difficult to determine the geologic situation. For this reason, a number of essential points, particularly in stratigraphy, remain obscure (e. g. the stratigraphic position of the Chapayev formation; Carboniferous stratigraphy, etc.). Still, thanks to the large scope of work, it was possible, even in a short field trip, to gain an idea of the main structural features of the region and of a number of ore deposits.

Information gained in this trip will be undoubtedly helpful to many participants in their future work.

COMPETITIONS FOR THE NAME PRIZES OF THE U. S. S. R. ACADEMY OF SCIENCES

The Section of Geologic and Geographic Sciences of the U. S. S. R. Academy of Sciences announces the 1961 competition for the following medals and prizes to be awarded by the Presidium:

1. The A. P. Karpinskiy Gold Medal for outstanding work in the general field of geology, paleontology, petrography, and industrial minerals.

2. The A. P. Karpinskiy Prize in the amount 20,000 rubles, for an outstanding work in geology, paleontology, petrography, and industrial minerals.

The deadline for the presentation of material for these competitions is October, 1961.

3. The A. Ye. Fersman Prize, in the amount 10,000 rubles for the best work in mineralogy and geochemistry. Deadline, August 1, 1961.

Competing material may be presented by scientific societies, scientific research institutes, schools of higher learning, construction bureaus, academicians, and corresponding members of the U. S. S. R. Academy of Sciences.

Only published works will be accepted for the competition.

Such works are to be presented at the Section of Geologic and Geographic Science, the U. S. S. R. Academy of Sciences (14 Leninskiy Prospect, Moscow V-71), inscribed, "For the competition for the ..... Prize", in two copies. They should be accompanied by criticism from the geologic fraternity, a short abstract, and a brief autobiography of the contestant, with a list of his main scientific works and inventions.

Section of Geologic and Geographic Sciences of the U. S. S. R. Academy of Sciences